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Long-Term Effects of Land Application of Domestic Wastewater: Dickinson, North Dakota, Slow Rate Irrigation Site

Benham-Blair and Affiliates, Inc, Oklahoma City, OK

Prepared for

Robert S Kerr Environmental Research Lab, Ada, OK

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Long-Term Effects of Land Application of Domestic Wastewater

Dickinson, North Dakota, Slow Rate Irrigation Site

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16. ABSTRACT

This report presents the findings of a study on the long-term effects of applying treated domestic wastewater to farmland at Dickinson, North Dakota. On the test site, slow rate irrigation, using the border-strip method, has been practiced since 1959. Water, soil, and crop samples from this test site were compared with similar samples from a nearby control site irrigated with well water. Samples were also taken to detect coliform bacteria.

Thirteen parameters were found to be present at significantly greater concentrations in the effluent used to irrigate the test site than in the river water used to irrigate the control site. Mean concentrations for five of the 13 parameters were found to be significantly greater statistically in the shallow alluvium aquifer beneath the test site than in the alluvium aquifer beneath the control site. These five parameters were chemical oxygen demand, chloride, nitrogen, potassium, and selenium. Except for selenium, the same parameters were also present at significantly greater concentrations in the deeper Sentinel Butte aquifer beneath the test site than in the Sentinel Butte beneath the control site. Total coliforms were occasionally found in control and test site wells.

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Dickinson, North Dakota, Slow Rate Irrigation Site

by

Benham-Blair & Affiliates, Inc.
Oklahoma City, Oklahoma 73120

and

Engineering Enterprises, Inc.
Norman, Oklahoma 73069

Contract No. 68-02-2363

Project Officer

Richard E. Thomas
Office of Water Program Operations
U.S. Environmental Protection Agency
Washington, D.C. 20460

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

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FOREWORD

The Environmental Protection Agency was established to coordinate the administration of major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities. As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs including the development and demonstration of soil and other natural systems for the treatment and management of municipal wastewaters.

Although land application of municipal wastewaters has been practiced for years, there has been a growing and widespread interest in this practice in recent years. The use of land application received major impetus with the passage of the 1972 amendments to the Federal Water Pollution Control Act. The 1977 amendments to the Act gave further encouragement to the use of land application and provided certain incentives for the funding of these systems through the construction grants program. With the widespread implementation of land application systems, there is an urgent need for answers to several major questions. One of these questions regards the long-term effects of land application on the soil, crops, groundwater, and other environmental components. This report is one in a series of ten which documents the effects of long-term wastewater application at selected irrigation and rapid infiltration study sites. These case studies should provide new insight into the long-term effects of land application of municipal wastewaters.

This report contributes to the knowledge which is essential for the EPA to meet the requirements of environmental laws and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

William C Galegar

William C. Galegar
Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

This report presents the findings of a study on the long-term effects of applying treated domestic wastewater to farmland at Dickinson, North Dakota. On the test site, slow rate irrigation, using the border-strip method, has been practiced since 1959. Water, soil, and crop samples from this test site were compared with similar samples from a nearby control site irrigated with well water. Samples were also taken to detect coliform bacteria.

Data on a number of parameters were evaluated against information about the natural features of the Dickinson physiographic region. Methods used in the field and laboratory analyses are described in sufficient detail to provide a basis for comparison of these results to other studies.

Key parameters that differ between control and test sites, such as nitrogen, phosphorus, and zinc, aid in assessing long-term effects of wastewater irrigation. An essential aspect of correctly evaluating water analyses is understanding the hydrogeology of the area. Knowledge of depth and movement of groundwater and location and thickness of aquifers was essential in interpreting data from wells strategically placed on both test and control sites.

Soil analyses from six depths at different seasons indicated a rapid renovation of the wastewater. In most cases, the upper layers of the soil [0-30 centimeters (cm)] adequately trapped chemicals such as phosphorus, which had higher concentrations in the wastewater than in the river water used for irrigation on the control site. Similarly, zinc, which serves as an indicator for other heavy metals, was effectively retained in the soil.

Thirteen parameters were found to be present at significantly greater concentrations in the effluent used to irrigate the test site than in the river water used to irrigate the control site. Mean concentrations for five of the 13 parameters were found to be significantly greater statistically in the shallow alluvium aquifer beneath the test site than in the alluvium aquifer beneath the control site. These five parameters were chemical oxygen demand, chloride, nitrogen, potassium, and selenium. Except for selenium, the same parameters were also present at significantly greater concentrations in the deeper Sentinel Butte aquifer beneath the test site than in the Sentinel Butte aquifer beneath the control site.

Total coliforms were occasionally found in both control and test site wells. However, no fecal coliforms were detected. The report concludes with a projection for 100 or more years of useful life for the site without undesirable effects from heavy metals, coliform bacteria, or excess nitrates in the groundwater. In addition, the site benefits from the extra plant

nutrients contained in the wastewater that are not present in the river irrigation water.

This report was submitted in partial fulfillment of Contract No. 68-02-2363 by Benham-Blair & Affiliates, Inc., as the principal contractor; Engineering Enterprises, Inc., as subcontractor; with three cooperating companies: Sheaffer and Roland, Inc.; D. E. Matschke Company; and W. J. Bauer Consulting Engineers, Inc., under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period from January, 1976, to November, 1977; work was completed as of July, 1978.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

acre-ft -- acre-foot
BOD -- biochemical oxygen demand
BOD_5 -- 5-day biochemical oxygen demand
cm -- centimeters
cm/hr -- centimeters per hour
COD -- chemical oxygen demand
DO -- dissolved oxygen
exch -- exchangeable
extr -- extractable
fecal coli -- fecal coliform
g -- grams
gal -- gallons
GL -- ground level
gpd -- gallons per day
gpd/ft -- gallons per day per foot
gpm -- gallons per minute
ha -- hectares
hr -- hours
in -- inches
in/hr -- inches per hour
kg -- kilograms
kg/ha -- kilograms per hectare
kg/ha/yr -- kilograms per hectare per year
km -- kilometers
L -- liters
L/s -- liters per second
L/d/m -- liters per day per meter
lb -- pounds
lb/acre -- pounds per acre
lb/acre/hr -- pounds per acre per hour
m -- meters
m^3 -- cubic meters
MCL -- maximum contaminant level
mg/g -- milligrams per gram
mg/L -- milligrams per liter
Mgal/d -- million gallons per day
Mgal/d/ft -- million gallons per day per foot
mi -- miles
mL -- milliliters
mm -- millimeters

mo -- month
ng/g -- nanograms per gram
ng/L -- nanograms per liter
nm -- nanometer
sq ft -- square feet
SR -- slow rate irrigation
SS -- suspended solids
SWL -- static water level
TDS -- total dissolved solids
TOC -- top of casing
total coli -- total coliform
yr -- year
μg/g -- micrograms per gram
μg/L -- micrograms per liter
μmhos/cm -- micromhos per centimeter
#/100 mL -- number of coliform per 100 milliliters of sample

SYMBOLS

Al -- aluminum
As -- arsenic
B -- boron
Ca -- calcium
Cd -- cadmium
Cl -- chlorine
Co -- cobalt
Cr -- chromium
Cu -- copper
Fe -- iron
Hg -- mercury
H_2SO_4 -- sulfuric acid
K -- potassium
Mg -- magnesium
Mn -- manganese
N -- nitrogen
Na -- sodium
NH_3 -- ammonia
NH_4 -- ammonium
Ni -- nickel
NO_2 -- nitrite
NO_3 -- nitrate
P -- phosphorus
Pb -- lead
S -- sulfur
Se -- selenium
SO_4 -- sulfate
Zn -- zinc
> -- greater than
< -- less than
μ -- micron

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Each of the participating companies had a primary leader or coordinator who took major responsibility for bringing the project to completion. They were Ernest L. Koerner for Benham-Blair and Affiliates, Inc.; D. Alan Haws for Engineering Enterprises, Inc.; Raymond H. Brand for Sheaffer and Roland, Inc.; and Donald E. Matschke for D. E. Matschke Company. Messrs. William J. Bauer, William H. Bellis, Keith E. Bennett, Paul K. Law, Geoffrey W. Leeper, Dennis G. Lund, Lelan K. Martin, Harold E. Namminga, W. Russell Street, Herbert M. Schornick, and John R. Sheaffer also made substantial contributions to the project.

In addition, the cooperation of the landowners and personnel from the city of Dickinson was appreciated.

SECTION 1

INTRODUCTION

Land application of domestic wastewater is not a new concept, although it has only been in recent years that land treatment has received renewed attention. This attention has been focused in two general areas: (1) economical wastewater renovation including increasing crop yields on agricultural soils; and (2) potential soil and groundwater pollution including potential health hazards. Decisions regarding wastewater management must consider these areas.

Proper design, operation, and monitoring of land application systems require data concerning the long-term effects of applying wastewater on land under a variety of conditions. There is a need for these data from areas where wastewater has been applied for at least 10 years.

For 17 years treated domestic wastewater from Dickinson, North Dakota, has been used for irrigation. The particular application method used is slow rate irrigation (SR) involving border strip flooding. This method is a controlled flooding process in which the irrigated area is divided into strips or channels by constructing border dikes or levees (Figure 1). The channels between the border dikes are wide and shallow, allowing irrigation water to flow from the head ditch in thin elongating sheets as it moistens the soil (Hagen et al., 1967).

In this research study, conducted over a one-year period, test and control plots were selected for comparison of certain parameters. Samples were collected of the sewage effluent, soils, groundwater, lagoon and river water, and plants. Field laboratory analyses of some samples at the site and later, complete chemical laboratory analyses provided the data presented in this report.

The objective of the study was to investigate the long-term effects of applying wastewater effluent to the land. Possible health hazards of heavy metal accumulation in plants; potential contamination of groundwater supplies with bacteria or excessive nitrates; and undesirable changes in the chemistry of the soil for maintaining high crop yields were key issues to be addressed in the study. The scope of the study consisted of one year of field investigation and focused attention on heavy metals, bacteria, nitrogen, and phosphorus.

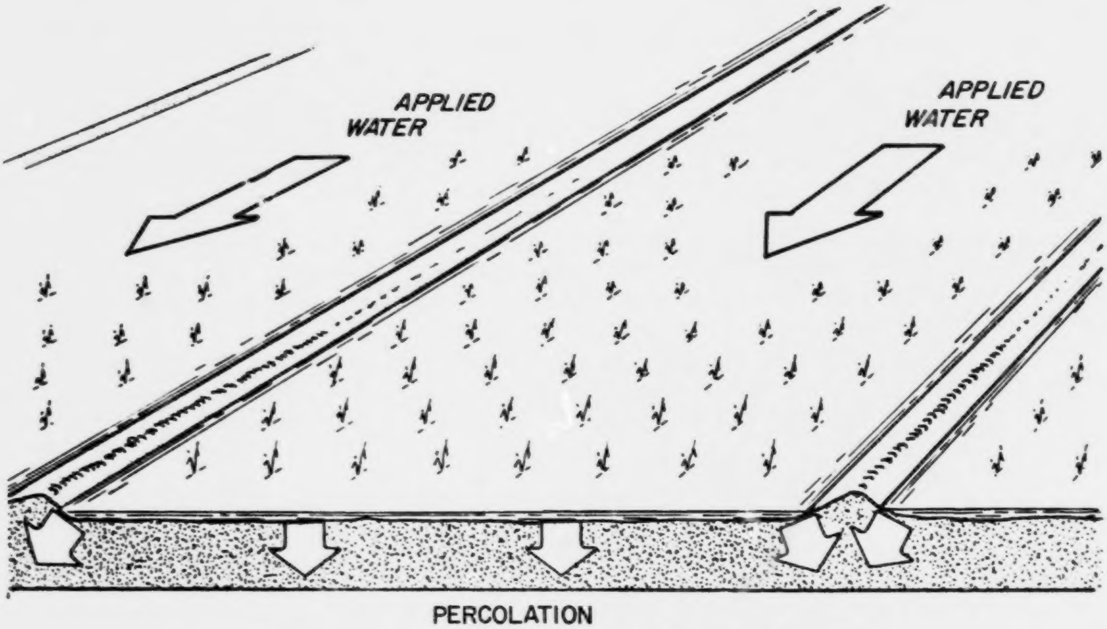

APPLIED WATER
APPLIED WATER
PERCOLATION

Figure 1. Border-strip flood irrigation.

SECTION 2

CONCLUSIONS

An analysis of the waters, soils, and plants at the Dickinson site has indicated that the use of wastewater for irrigation resulted in several long-term beneficial effects. The specific major findings showed that:

1. Although total coliform bacteria were found at both the control and test sites, no fecal coliform bacteria were found in any wells. There is no direct evidence of total or fecal coliform bacteria penetration of soils after 17 years of irrigation with effluent from the Dickinson, North Dakota, wastewater treatment plant.

2. There is no evidence that coliform bacteria contamination of the grass crop is occurring as a result of irrigation with effluent. Total and fecal coliform bacteria found at the control and test sites were attributed to cattle that are pastured at both sites.

3. Metals such as zinc, copper, and chromium that were measured in small concentrations in the effluent were removed and continue to be sufficiently immobilized by the soil after 17 years of irrigation. Sodium, zinc, and manganese concentrations have shown some increase in the effluent-irrigated crop contrasted with the Heart River water-irrigated crop at the control site but were well within the normal range for grass crops.

4. Toxic metals such as cadmium, lead, and mercury have been demonstrably absent in the effluent, the groundwater, and the irrigated grass crop.

5. After irrigation for 17 years, the small effluent concentration of copper, arsenic, zinc, and manganese has not greatly contributed to the soil concentration of these metals. The Heart River water used for irrigation at the control site has comparable concentrations of these metals. The slightly greater concentrations of copper, arsenic, zinc, and manganese that were observed in the test site soils were attributed to natural soil conditions.

6. Extractable metals in the test site soils, such as boron, were adequate for crop nutrition, below toxic levels, and comparable with extractable concentrations generally found in agricultural soils.

7. No harmful concentrations of the herbicides and pesticides endrin,

lindane, methoxychlor, toxaphene, 2,4-D, and 2,4,5 TP silvex were present in the effluent or groundwater. The average ranges of concentrations in the control and test sites groundwater were comparable to each other.

8. Chemical oxygen demand concentrations of groundwater exiting the test site and discharging to the Heart River were consistent with the concentrations observed in the Heart River water upstream of the site and with concentrations in the Dickinson water supply.

9. The plant nutrients nitrogen and phosphorus have both appeared to increase in the test site soils when compared with the control site soils.

10. Nitrate plus soluble organic nitrogen are exiting the test site in the underlying groundwater at an average concentration of 3.0 milligrams/liter (mg/L). This compares to the average concentration of 1.1 mg/L for nitrate plus soluble organic nitrogen in the control site groundwater. The 1.9 mg/L difference represents about 17 percent of the nitrogen applied by the effluent.

11. Nitrogen loss to volatilization and denitrification is projected to be in the range of 22 percent at the test site.

12. Phosphorus uptake by the test site soils has been contained in the upper 40 cm [16 inches (in)] of the soil profile after 17 years of effluent application and phosphorus is reduced to an average 0.06 mg/L soluble phosphorus in the underlying groundwater. The projected life for continued phosphorus removal for the test site soil is in excess of 100 additional years.

13. All parameters observed for the groundwater, soils, and plants support the continued use and longevity for the test site, for continued effluent irrigation crop benefits, and for continued wastewater reclamation.

SECTION 3

SITE-SELECTION PROCESS

GENERAL CRITERIA

Earlier Approaches

An earlier report (Bauer, 1976) defined a number of working approaches for the site-selection process. These were used initially to provide direction in the data-gathering phases. The earlier approaches included the following:

Soil Chemistry--
The chemical reaction of the soil with the chemicals in the applied wastewater takes place first in the upper layers of the soil. After these upper or plow layers have become saturated, reactions take place at progressively lower elevations. The distribution of accumulated chemicals resulting from the application of wastewater is studied from the point of view of this simple model of the process.

Biological--
Some of the materials applied to the land in the wastewater are removed in the form of crops. To calculate an overall materials balance, an estimate of the total quantity of materials removed by crops must be made.

Hydrological--
Water moves through the earth in two major forms: (1) as soil water through the unsaturated zone, where the two fluid properties of fluid weight and surface tension dominate the movements, and (2) as groundwater through the saturated zone, where the two fluid properties of fluid weight and viscosity dominate the movements. Both of these movements are subject to the laws of fluid mechanics, permitting mathematical models to be set up for a particular site.

Such models are useful in guiding the exploratory and sampling program and in interpreting the results of such programs. The models enable one to define a "plume" of water that originates in the wastewater application site. This plume is then the only part of the soil and groundwater that is affected by the application of the wastewater. All other water outside this plume remains unaffected. This is an extremely important concept in guiding the program of sampling and in interpreting the results.

Application to Sites

The foregoing approaches aid in defining parameters that help to distinguish one site from another. Several of these parameters are as follows:

Uniform Permeability of Soils--

Each test site and control site should have the same type of soil with the same general, reasonably uniform permeability. The soil should not contain any well-defined channels through which the applied water could escape without contact with the chemicals in the soil mass.

Same Site--

The same site should have been used for a long time. If wastewater had been applied to first one and then another site over the period of operation, the concept of the long-term effect would not be applicable.

Depth to Groundwater--

The depth to the groundwater should be sufficient to permit good crop production, yet shallow enough to allow economical sampling of the water. The thickness of the aquifer should be adequate to permit a large body of soil to react with the applied wastewater.

Accounting for Chemical Elements--

Sufficient data should be available to estimate the total mass of chemical elements applied with the wastewater, the amount percolated through the soil, the amount taken off in the crops, and the amount that has remained in the soil.

Constant Quality--

No substantial change should have occurred in the chemical quality of the applied wastewater over the period being studied.

Extraneous Sources--

If chemicals other than those in the wastewater have been applied on the study sites, such an application can introduce uncertainties into the operation that would make the analyses difficult. Other factors being equal, sites at which other sources of chemicals have been applied should be avoided.

General Criteria Supplied by EPA

The EPA also specified certain other general criteria for the selection of sites. These criteria are as follows:

1. Flow rates should be at least 4.38 liters/second (L/s) [0.1 million gallons/day (Mgal/d)].
2. Historical records should be available for at least 10 years.
3. The applied wastewater should be effluent from either primary or secondary treatment.
4. A good control site should be available within a reasonable

distance and have the same general type of soil and hydrogeological conditions.

NORTHERN HIGH PLAINS SITES

Preliminary Evaluations

The geographical area involved was the High Plains portion of the states of Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, and Kansas. STORET data supplied by the EPA were examined for information about potential sites in each of these states. A survey was conducted to obtain further information about these sites and any others that might be candidates for study. Golf course sites were arbitrarily eliminated. Also eliminated were sites in which the wastewater was mixed with other water prior to irrigation. Because this was a common practice throughout the region, few sites were available for further study.

The Dickinson site was the only site in the Northern Plains states that warranted further investigation. Other potential sites were eliminated on the basis of information obtained from the survey and literature review for the reasons listed in Table 1.

Site Visit

Only the Dickinson site was visited. Both the test site and the control site were located in the section that contains the lagoon treatment system of the city of Dickinson. The control site is irrigated with river water, while the test site irrigation water is effluent from a lagoon.

TABLE 1. POTENTIAL IRRIGATION SITES AND REASONS FOR REJECTION

Sites	Reasons for Rejection
Scott City, Kansas	Wastewater mixed with other water sources
Shelby, Nebraska	
Cheyenne, Wyoming	
Gillette, Wyoming	
Rawlins, Wyoming	
Air Force Academy, Colorado	Golf course or landscape irrigation only
Colorado Springs, Colorado	
Fitzsimmons, Colorado	
Grand Forks, North Dakota	
Minot, North Dakota	
Wray, Colorado	System discontinued
Fort Carson, Colorado	System too new
Inverness Sanitary District, Denver, Colorado	
Sublett, Kansas	
South Dakota	No irrigation with municipal effluent

SECTION 4

DESCRIPTION OF SITE

GENERAL

Dickinson is located at map coordinates latitude 46°47'N, longitude 102° 49'W in Stark County in southwestern North Dakota (Figure 2). The city had a population of 13,400 in 1975 and has one institution of higher education, Dickinson State College. Dickinson is primarily a service business center for the agriculture and ranching needs of the area. It has one of the largest cattle auctions in the upper Great Plains. The lack of an adequate water supply precludes the development of any major water-using industries.

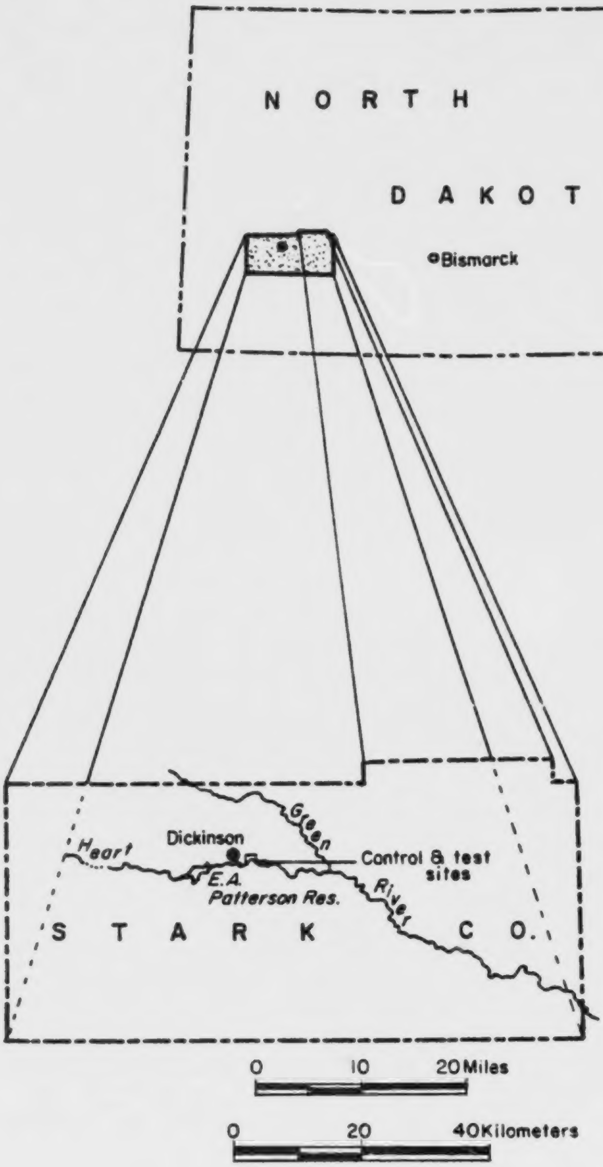
TOPOGRAPHY

The county consists of gently sloping to steep upland prairie that is bordered on the west by the Badlands (Theodore Roosevelt National Memorial Park - South Unit). The rolling plateau has been dissected by the channels of the main streams and by many intermittent waterways. Scattered buttes, capped by resistant sandstone or limestone, are remnants of sedimentary strata that once covered the area more extensively. Antelope Creek, the Heart River, and the Green River are the principal natural streams. There are no other significant natural bodies of water, but many artificial impoundments have been constructed since 1940 to provide water for livestock and recreational purposes. The major impoundment is the E. W. Patterson Lake on the Heart River near the southwestern limit of Dickinson. This reservoir is capable of storing 850,000,000 cubic meters (m^3) [6,900 acre-feet (ft)] and provides water for municipal use and irrigation. The flow of the Heart River is intermittent, with a maximum of 197,390 L/s [6,970 cubic ft per second (ft^3/s)].

Dickinson is at an elevation of 732 m (2,400 ft) above mean sea level, and the local relief varies across the city by about 50 m (164 ft). The area within the city slopes in a south-southeasterly direction to the Heart River.

TEST SITE

The test site consists of about 5.7 hectares (ha) (14 acres) and is located to the south of the wastewater lagoons (Figures 3 and 4). It lies adjacent to the Heart River and is bordered on the east by a diked dirt road and the channel of the Heart River. The channel is about 5.5 m (18 ft) deep. It is bordered on the west and south by a steep hill approximately 7 m (2 ft) high. Between the second cell of the wastewater lagoons and the test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Control & test sites
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0 10 20 Miles
0 20 40 Kilometers

Figure 2. Location of Stark County.

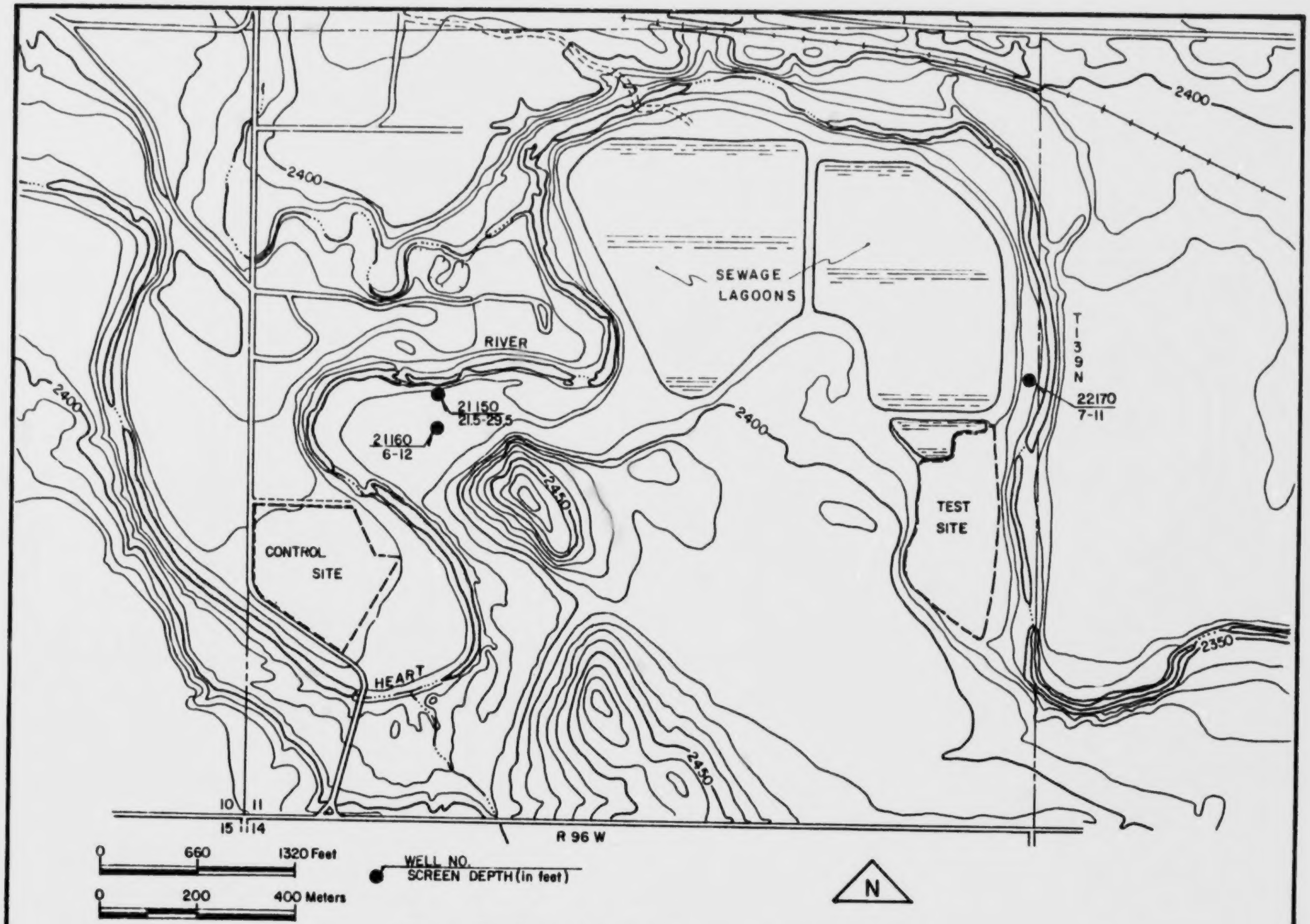

2400
2400
2400
2400
2350
2450
2450
SEWAGE LAGOONS
RIVER
HEART
TEST SITE
CONTROL SITE
T 139 N
22170
7-11
21150
21.5-29.5
21160
6-12
10 11
15 14
R 96 W
0 660 1320 Feet
0 200 400 Meters
WELL NO.
SCREEN DEPTH (in feet)
N

Figure 3. General location map, Dickinson, N.D.

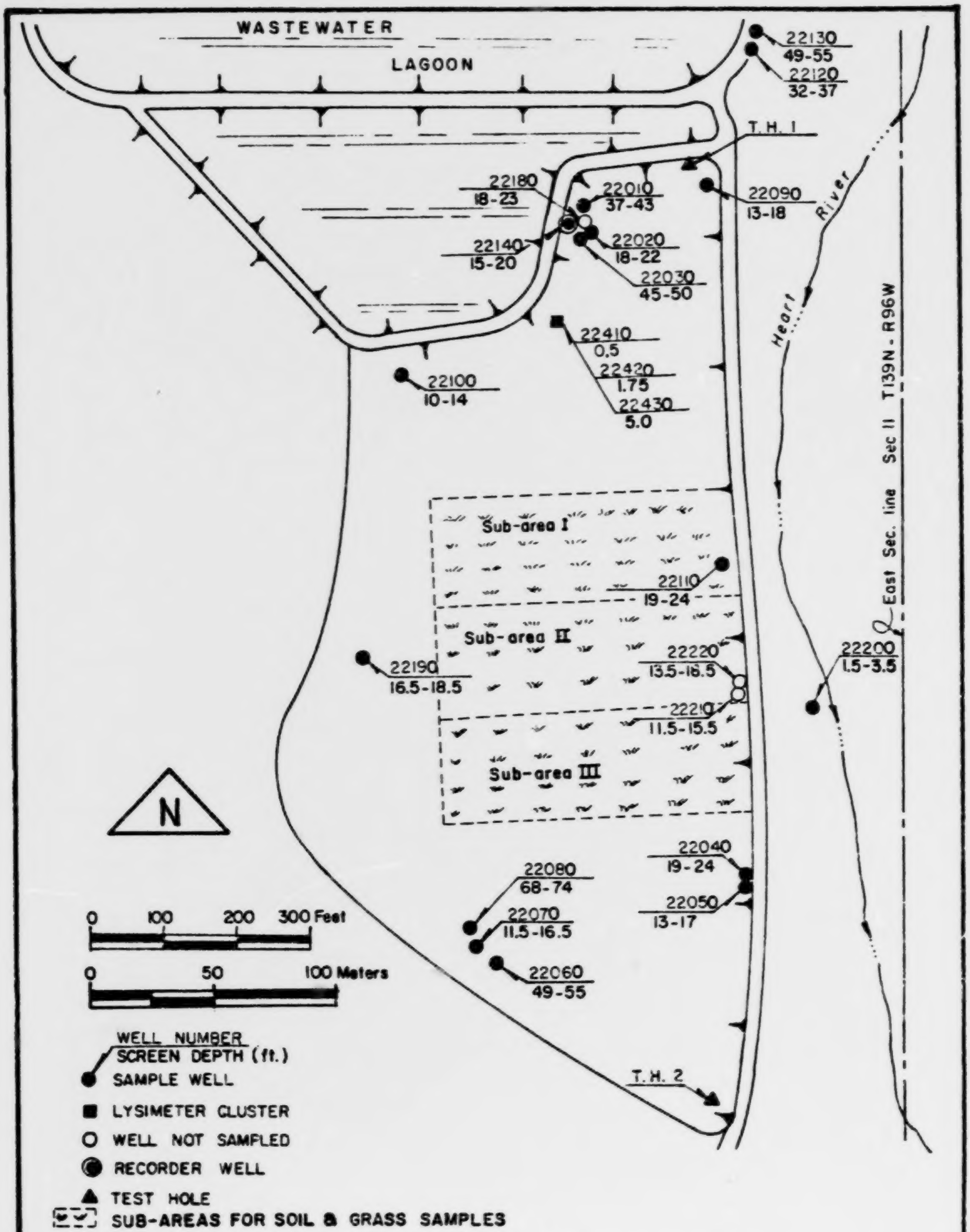

WASTEWATER
LAGOON
22130
49-55
22120
32-37
T. H. I
22180
18-23
22010
37-43
22090
13-18
22140
15-20
22020
18-22
22030
45-50
22410
0.5
22420
1.75
22430
5.0
22100
10-14
River
Heart
East Sec. line Sec 11 T139N. R96W
Sub-area I
22110
19-24
Sub-area II
22190
16.5-18.5
22220
13.5-16.5
22210
11.5-15.5
22200
1.5-3.5
Sub-area III
N
22040
19-24
22080
68-74
22050
13-17
22070
11.5-16.5
22060
49-55
0 100 200 300 Feet
0 50 100 Meters
WELL NUMBER
SCREEN DEPTH (ft.)
SAMPLE WELL
LYSIMETER CLUSTER
WELL NOT SAMPLED
RECORDER WELL
TEST HOLE
SUB-AREAS FOR SOIL & GRASS SAMPLES
T. H. 2

Figure 4. Wastewater irrigation test site.

site is a small holding lagoon. The land to the west and above the test site has been sprinkler-irrigated with wastewater since 1966. The test site has been flood-irrigated with wastewater from the holding lagoon since 1959. The field was leveled in 1971 and is now flood-irrigated by the border-strip method.

CONTROL SITE

The control site is located about 1.3 kilometers (km) [0.8 miles (mi)] west and upstream of the test site (Figures 3 and 5). It is bordered on two sides by the Heart River and slopes gently to the east. The land has been flood-irrigated by the border-strip method since the 1940s with water pumped from the Heart River. On the southwest side of the control site is a 4.5 ha (11 acre) plot that is also flood-irrigated with water from the Heart River, as is the farmland located to the northwest of the control site. About 1.2 km (0.75 mi) north of the control site are several cattle auction barns with holding pens having surface drainage to the southeast, downstream of the control site. Stormwater drainage from the town is discharged at various points into the Heart River. There is little municipal or industrial wastewater discharge upstream of the control site.

GROUNDWATER HYDROLOGY AND GEOLOGY

The Heart River heads in the western part of Stark County and cuts a meandering channel in an east-southeasterly direction across the county. Both test and control sites are in the unglaciated portion of the Great Plains physiographic province. The land immediately surrounding both sites is a highly dissected rolling plateau with several hundred feet of relief over horizontal distances of about a mile.

According to a recent publication, both sites are on the southeast limb of a northeast-southwest trending synclinal structure (Trapp and Croft, 1975). Thus, the surface rock beneath and surrounding the test and control sites dips gently to the northwest.

Test Site

All of the test site is underlain by alluvial deposits of the Heart River. This alluvium consists of clays, silts, very fine to fine sands, and occasional lenses of coarse sand and gravel. Fragments of coal and lignite are common throughout the alluvial sediments.

Beneath the alluvium is the Sentinel Butte Formation, which is the upper stratigraphic unit of the Fort Union Group and is Upper Paleocene in age. The Sentinel Butte crops out in the hills surrounding the site, and on the higher ridges it is overlain by the Golden Valley Formation of Eocene age. Sediments that make up the Sentinel Butte consist of interbedded fine-grained sandstones and siltstones, and claystones with thin partings of lignite. Sandstones and siltstones of the Sentinel Butte Formation are generally dark blue, and the claystones are gray to white. The claystones in the Sentinel Butte are reported to be bentonitic (Trapp and Croft, 1975), and it seems reasonable to assume that the alluvial clays are predominantly bentonitic.

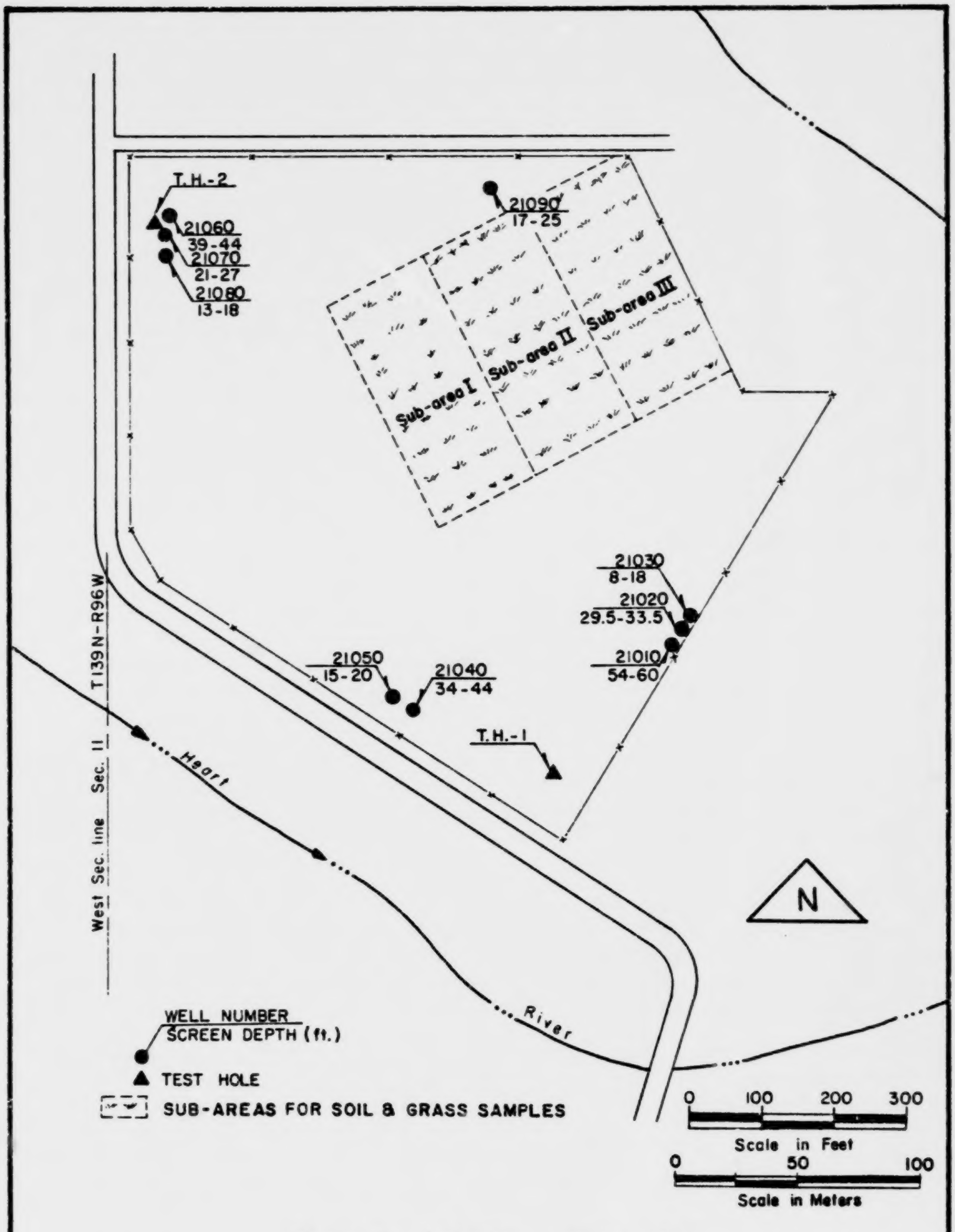

T.H.-2
21060
39-44
21070
21-27
21080
13-18
21090
17-25
Sub-area I
Sub-area II
Sub-area III
21030
8-18
21020
29.5-33.5
21010
54-60
21050
15-20
21040
34-44
T.H.-1
T139N-R96W
West Sec. line Sec. 11
Heart
River
N
WELL NUMBER
SCREEN DEPTH (ft.)
TEST HOLE
SUB-AREAS FOR SOIL & GRASS SAMPLES
0 100 200 300
Scale in Feet
0 50 100
Scale in Meters

Figure 5. Irrigation control site.

No sharp distinction exists at all locations between the alluvium and the underlying Sentinel Butte. Sediments of the Sentinel Butte are semiconsolidated, and the poorly cemented to noncemented sandstones and siltstones have a drilling penetration rate about the same as that for the alluvial sediments. For this study the alluvial-bedrock contact was picked at a color change, a cemented sandstone, or a claystone.

The Sentinel Butte can be 137 m (450 ft) thick, with this maximum thickness occurring south of Dickinson (Trapp and Croft, 1975). The test drilling penetrated only a part of the Sentinel Butte. Monitoring well 22030, on the northern end of the test site, was drilled 11 m (36 ft) into the Sentinel Butte. At the south end of the test site, monitoring well 22080 was drilled 18 m (59 ft) into the Sentinel Butte, the deepest penetration of this stratigraphic unit (Figure 4).

The groundwater aquifer system beneath the test site can be characterized as alluvial and bedrock. The alluvial aquifer consists of predominantly fine-grained clastics with only thin, scattered accumulation of gravel and medium to coarse sand. The summer water-level contours for the alluvial aquifer (Figure 6) are from the July, 1976, data. These data suggest mounding of groundwater beneath the lagoon area. Water-level measurements were made during the irrigation season when the irrigation holding lagoon was full of wastewater. There is a noticeable bulge of the mound toward the southeast, indicating movement across the test site toward the Heart River. Some of this mounding is due to leakage of the irrigation holding lagoon because the ground adjacent to the perimeter of the holding lagoon dike was saturated and marshy. Very little rain fell during this period and the mounding must be due to wastewater irrigation and lagoon leakage (Figure 7). The irrigation holding lagoon was dry during and before these measurements. Therefore, residual mounding is probably due to minor leakage of the wastewater lagoon cells because very little rainfall is recorded in the Dickinson area during the fall, winter, and early spring months (Table 2). The hydrograph for well 22140 generally supports this observation, although the rise in the alluvial water level in April does not fit the irrigation or rainfall data. However, there were several inches of snowfall on the ground during the winter months and as late as the first part of April. The melting of the snow and release of frozen ground moisture following the spring thaw probably account for the rise in alluvial water shown for April, 1977 (Figure 7).

An alluvial aquifer pump test was conducted at the north end of the test site. Well 22020 was the pumping well, and wells 22140 and 22180 were observation wells (Figure 4). The principal groundwater movement probably occurred in the thin sand and gravel zone that overlies the Sentinel Butte Formation (Figure 8). The distance-drawdown data from a six-hour test suggested a coefficient of transmissibility of about 24,800 liters per day per meter (L/d/m) (2,000 gpd/ft). The calculated storage coefficient is approximately 0.1, which is reasonable for a watertable aquifer. Calculation of the field coefficient of permeability from the above data and the alluvial saturated thickness gives a value of approximately 6,100 L/d/m^2 (150 gpd/ft^2). If the effective porosity of the alluvium is assumed to be 20 percent, the groundwater velocity across the test site ranges from <0.8 to 1.5 m (<3 to 5 ft) per day. The contour lines (Figure 4) indicate that the slope of the water table and the flow across the site are about twice as great at the north end as at the south end.

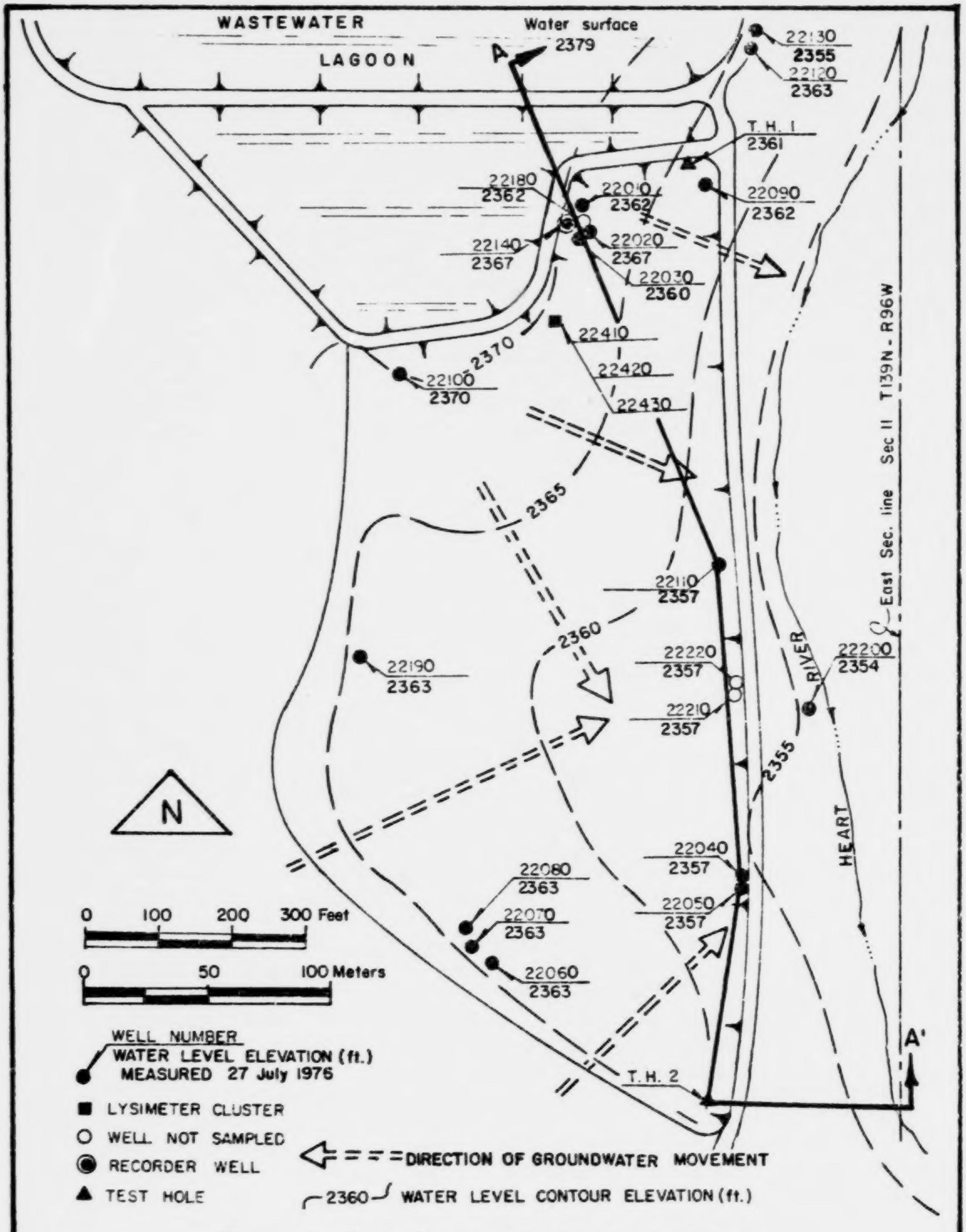
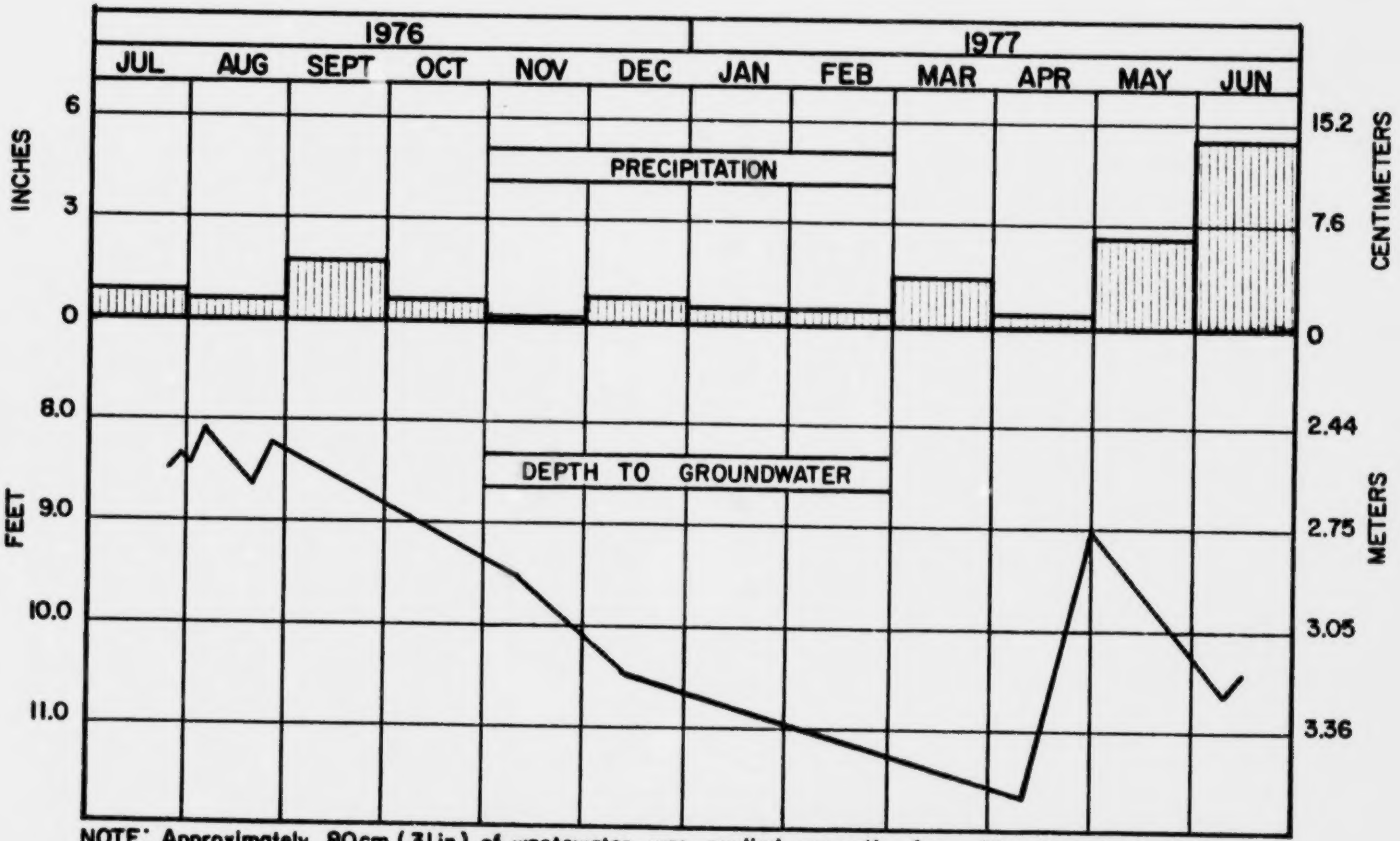

WASTEWATER
LAGOON
Water surface
2379
A
A'
22130
2355
22120
2363
T. H. 1
2361
22180
2362
22010
2362
22090
2362
22140
2367
22020
2367
22030
2360
22410
22420
22430
2370
22100
2370
2365
22110
2357
2360
22220
2357
22210
2357
22200
2354
22190
2363
2355
RIVER
HEART
East Sec. line Sec 11 T139N. R96W
N
22040
2357
22050
2357
22080
2363
22070
2363
22060
2363
T. H. 2
0 100 200 300 Feet
0 50 100 Meters
WELL NUMBER
WATER LEVEL ELEVATION (ft.)
MEASURED 27 July 1976
■ LYSIMETER CLUSTER
○ WELL NOT SAMPLED
◉ RECORDER WELL
▲ TEST HOLE
DIRECTION OF GROUNDWATER MOVEMENT
2360 WATER LEVEL CONTOUR ELEVATION (ft.)

Figure 6. Test site groundwater level contours.



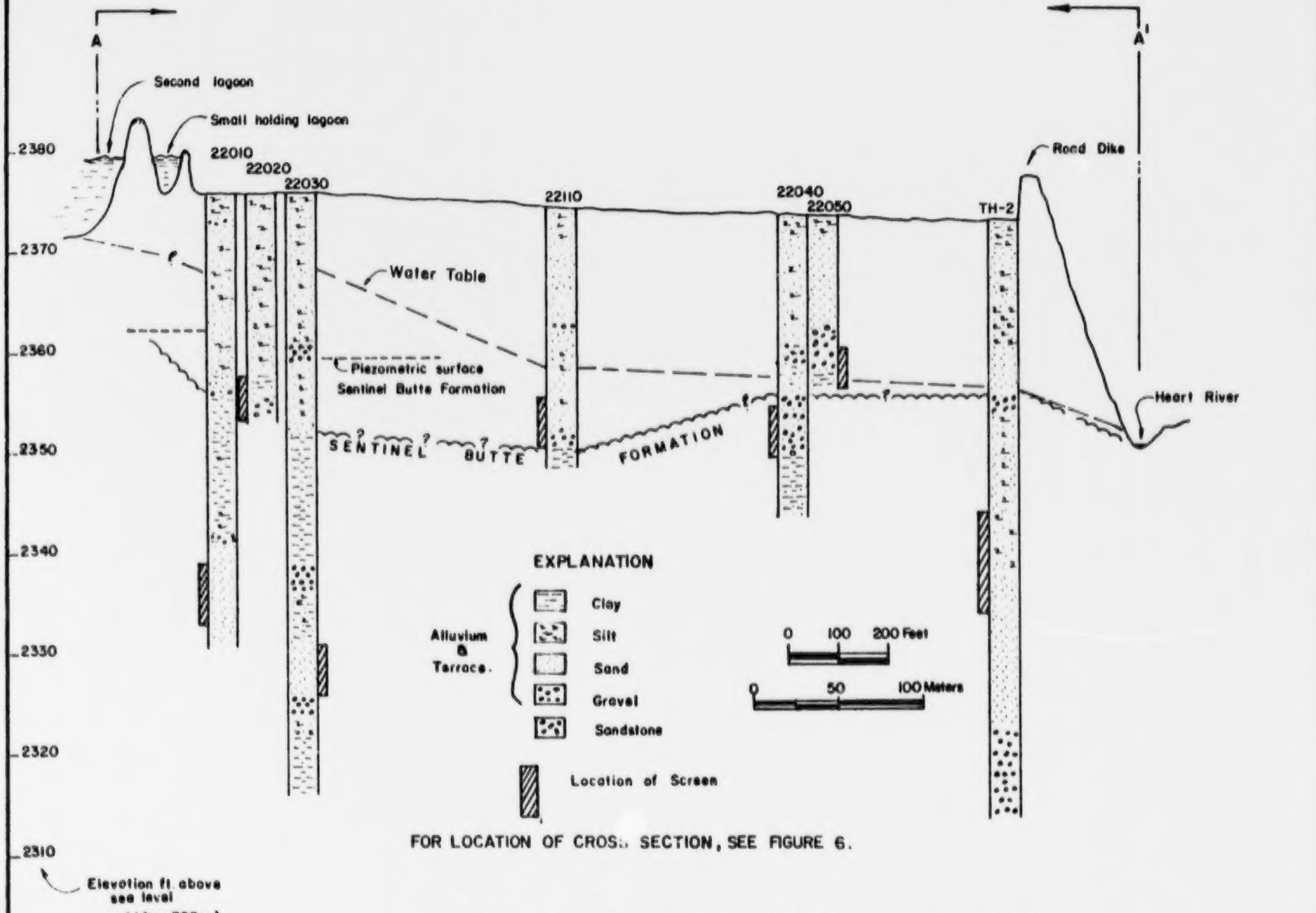
NOTE: Approximately 80cm (31in) of wastewater was applied annually from May through August. Depth to groundwater measured at well 22140.

Figure 7. Test site hydrologic cycle.

TABLE 2. MEAN MONTHLY TEMPERATURES AND PRECIPITATION, DICKINSON EXPERIMENT STATION, NORTH DAKOTA

Month	Temperature °F					Mean Degree Days Base 65° F	Precipitation in Inches					Mean No. of Days Precipitation 0.10 Inch or More
	Means			Extremes					Snow, Sleet			
	Daily Maximum	Daily Minimum	Monthly	Record Highest	Record Lowest		Mean	Greatest Daily	Mean	Maximum Monthly	Greatest Daily	
Jan	22.6	0.7	11.0	59	-44	1670	0.44	0.45	4.9	18.2	7.0	2
Feb	24.9	1.9	13.4	67	-47	1440	0.44	0.75	4.8	12.9	8.0	1
Mar	36.4	14.1	25.3	85	-33	1230	0.74	1.03	6.3	19.4	9.0	2
Apr	54.9	28.4	41.7	92	-19	700	1.24	1.95	3.3	17.0	10.0	3
May	66.3	39.2	52.8	106	11	410	2.20	2.67	1.2	12.8	10.0	5
Jun	74.6	48.9	61.8	109	28	160	3.50	4.03	<0.1	4.0	4.0	7
Jul	83.8	54.1	69.0	114	29	60	2.17	4.03	0.0	0.0	0.0	5
Aug	82.4	51.5	67.0	110	24	60	1.78	2.54	0.0	0.0	0.0	4
Sep	71.3	41.0	56.2	104	12	290	1.19	2.10	0.2	6.0	5.0	3
Oct	58.1	30.5	44.3	93	-15	640	0.85	1.46	2.3	26.9	10.0	3
Nov	40.1	17.6	28.9	78	-23	1080	0.55	1.40	4.7	28.0	14.0	2
Dec	27.9	6.3	17.1	68	-37	1480	0.40	0.64	4.0	15.8	6.0	1

Source: U.S. Weather Bureau Climatological Summary No. 20-32. Average length of record ≥60 years.


A
A'
Second lagoon
Small holding lagoon
22010
22020
22030
22110
22040
22050
TH-2
Road Dike
Heart River
Water Table
Piezometric surface Sentinel Butte Formation
SENTINEL ? BUTTE ? FORMATION
2380
2370
2360
2350
2340
2330
2320
2310
Elevation ft. above sea level (1ft.= .305m)
EXPLANATION
Alluvium & Terrace.
Clay
Silt
Sand
Gravel
Sandstone
Location of Screen
0 100 200 Feet
0 50 100 Meters

FOR LOCATION OF CROSS SECTION, SEE FIGURE 6.

Figure 8. Cross section A-A' of lagoons and test site.

Groundwater in the northern portion of the test site that moves across the site is, during the summer, a mixture of lagoon water (from leakage), applied wastewater (percolated through the soil), and groundwater from the upper Sentinel Butte (upstream from the test site). Groundwater moving across the test site in the southern half of the site is a mixture of irrigation-applied wastewater and groundwater inflow from the upper Sentinel Butte south and southeast of the site.

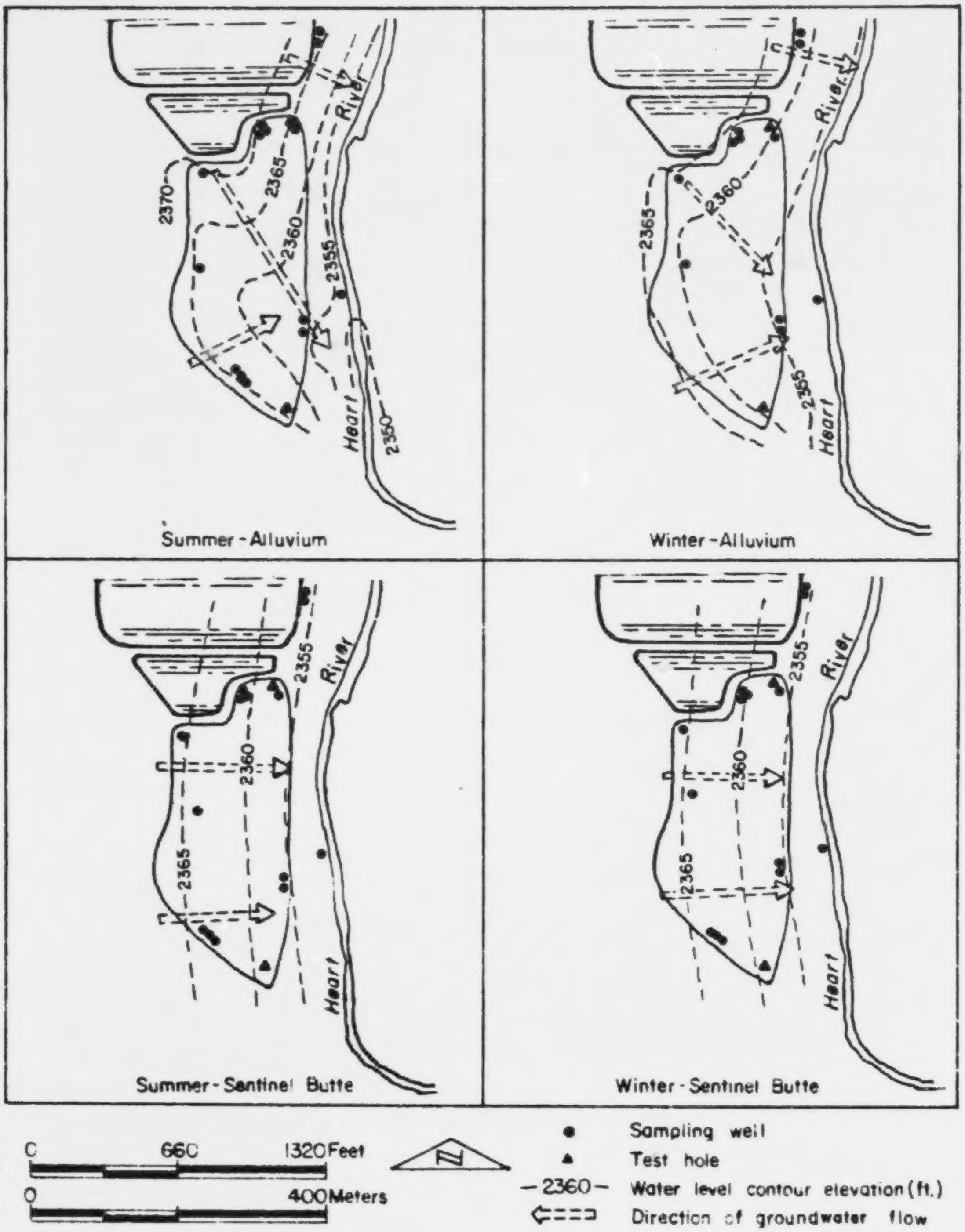
The underlying Sentinel Butte Formation is hydraulically separated from the overlying alluvium. This is shown on cross section A-A' (Figure 8) near the lagoon area, where the piezometric surface of the Sentinel Butte is several feet below the alluvial water table. This distinction decreases away from the lagoon, and the two surfaces are nearly the same over the remainder of the site. The fine-grained character and well-cemented sands of the Sentinel Butte limit the permeability of this bedrock unit. Although no pump test was conducted for this part of the Sentinel Butte, the pump rates noted during the water sampling phase indicated water-yielding capabilities generally equivalent to those of the alluvium. Transmissibility values have been reported as ranging from 37,000 to 74,000 L/d/m (3,000 to 6,000 gpd/ft) and storage coefficient values between 0.0007 and 0.0008 (Trapp and Croft, 1975). Contours of the piezometric surface for the Sentinel Butte measured in July, 1976, are shown in Figure 8, and there was essentially no change in these data for the April, 1977, measurements. The groundwater contours for the alluvium and Sentinel Butte Formation are shown for both summer and winter in Figure 9.

Control Site

The hydrogeology at the control site is very similar to that of the test site. However, at the control site there seems to be a hydraulic connection between the alluvium and the underlying Sentinel Butte Formation. The alluvial sediments are thin, 2.5 to 3.4 m (8 to 11 ft) at well locations 21060, 21070, and 21080, and there is not a significant impermeable layer between the two aquifers. In fact, the alluvial sands and gravels are resting directly on the Sentinel Butte sandstone. Therefore, the two-aquifer system that is present at the test site is a very leaky aquifer system at the control site. Figure 10 suggests mounding of the alluvial groundwater due to irrigation and a flow pattern in all directions from the site. The winter measurements showed the mound had flattened approximately 1.8 to 2.5 m (6 to 8 ft).

The summer water level for the Sentinel Butte Formation is lower than that for the alluvium (Figure 11). In the winter the Sentinel Butte water level drops 1.2 to 1.8 m (4 to 6 ft) in response to alluvial leakage and assumes a level similar to that of the alluvial groundwater (Figure 11). These water-level data support the concept of the interaction of the two aquifers.

Because the control site is located in the meander loop, there is probably only minor groundwater inflow from the Sentinel Butte Formation at higher elevations to the north of the site. The chief source of groundwater in



Summer - Alluvium

Winter - Alluvium

Summer - Sentinel Butte

Winter - Sentinel Butte

2370
2365
2360
2355
2350
Heart
River
0
660
1320 Feet
400 Meters
N
● Sampling well
▲ Test hole
— 2360 — Water level contour elevation (ft.)
⇦⇠ Direction of groundwater flow

Figure 9. Seasonal test site groundwater level contours.

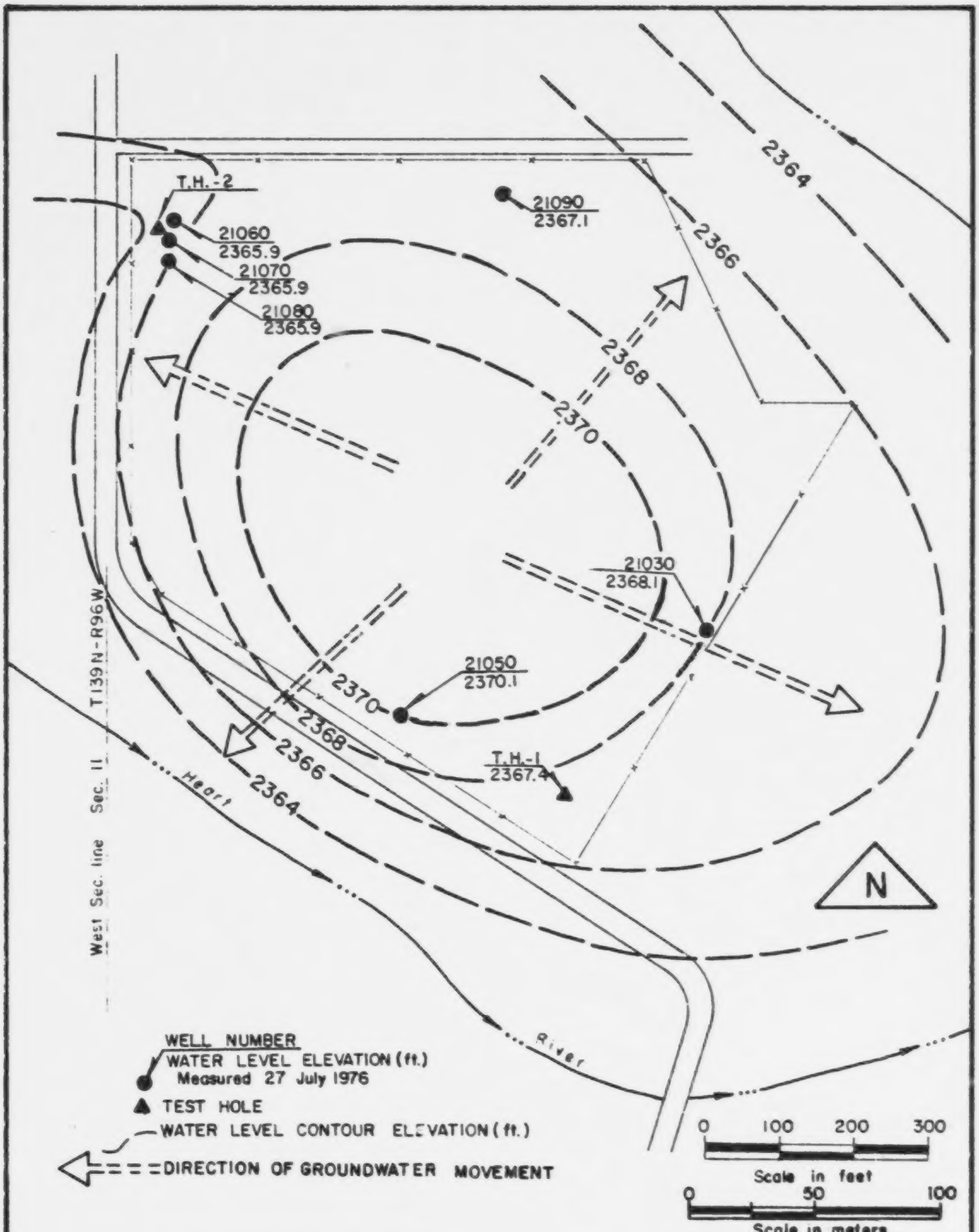

T.H.-2
21060
2365.9
21070
2365.9
21080
2365.9
21090
2367.1
2364
2366
2368
2370
21030
2368.1
21050
2370.1
T.H.-1
2367.4
Heart
River
T139N-R96W
West Sec. line Sec. 11
N
WELL NUMBER
WATER LEVEL ELEVATION (ft.)
Measured 27 July 1976
TEST HOLE
WATER LEVEL CONTOUR ELEVATION (ft.)
DIRECTION OF GROUNDWATER MOVEMENT
0
100
200
300
Scale in feet
0
50
100
Scale in meters

Figure 10. Control site groundwater level contours.

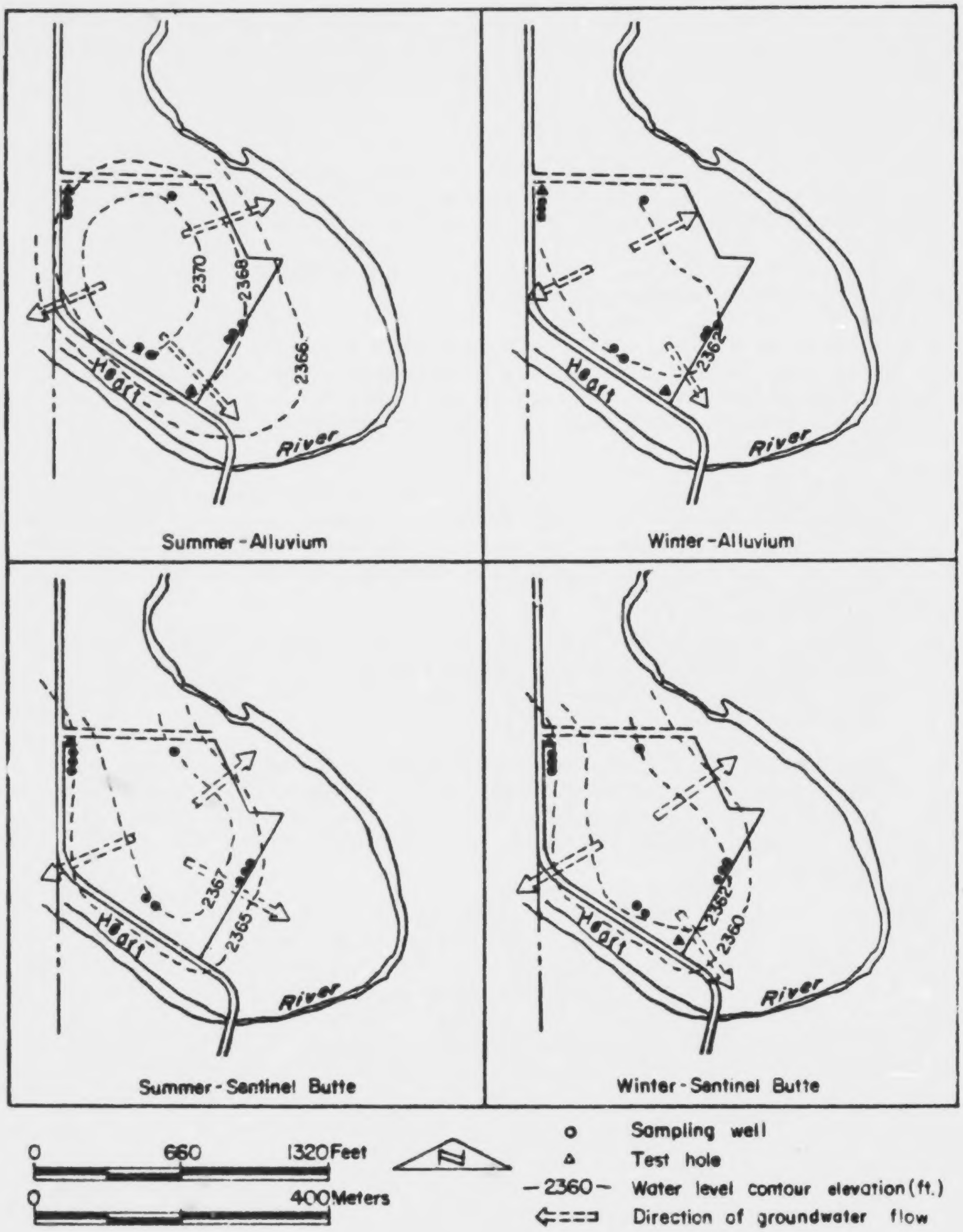

2370
2368
2366
Heart
River
Summer - Alluvium
2362
Heart
River
Winter - Alluvium
2367
2365
Heart
River
Summer - Sentinel Butte
2362
2360
Heart
River
Winter - Sentinel Butte
0
660
1320 Feet
0
400 Meters
N
o Sampling well
Δ Test hole
— 2360 — Water level contour elevation (ft.)
⇐=== Direction of groundwater flow

Figure 11. Seasonal control site groundwater level contours.

the Sentinel Butte at the control site is downward movement of the alluvial water. The source of most of the alluvial groundwater can be attributed to the irrigation water pumped from the Heart River.

SOILS

The soils at the Dickinson sites are deep, sandy, alluvial deposits in the bottomlands of the Heart River Valley. Originally these lands were gently undulating and required some leveling for flood irrigation.

A profile description, typical of both the control site and the test site before leveling occurred, follows:

> A1-0-13 cm (0-5.1 in); dark grayish brown (2.5Y4/2) fine sandy loam, very dark grayish brown (2.5Y3/2) when moist; weak, fine, angular blocky structure or single grain; soft when dry, very friable when moist, nonsticky and nonplastic when wet; noncalcareous; clear, smooth boundary.
>
> C1-13-28 cm (5.1-11.0 in); grayish brown (2.5Y5/2) loamy fine sand, very dark grayish brown (2.5Y3/2) when moist; weak, coarse, prismatic to moderate, angular blocky structure; soft when dry, loose when moist, nonsticky and nonplastic when wet; slightly calcareous; gradual wavy boundary.
>
> C2-28-40 cm (11.0-15.7 in); grayish brown (2.5Y5/2) loamy fine sand, dark grayish brown (2.5Y4/2) when moist; single grain; loose both when dry and moist, nonsticky and nonplastic when wet; noncalcareous; clear wavy boundary.
>
> C3-40-53 cm (15.7-20.9 in) grayish brown (2.5Y5/2) fine sandy loam, dark grayish brown (2.5Y4/2) when moist; moderate, fine and coarse, angular blocky structure; slightly hard when dry, very friable when moist, nonsticky and nonplastic when wet; calcareous; clear wavy boundary.
>
> C4-53-65 cm (20.9-25.6 in) grayish brown (2.5Y5/2) fine sandy loam, dark grayish brown (2.5Y4/2) when moist; weak, medium and coarse, angular blocky structure; soft when dry, very friable when moist, nonsticky and nonplastic when wet; calcareous; clear wavy boundary.
>
> C5-65-89 cm (25.6-35.0 in) (auger sample); grayish brown (2.5Y5/2) very fine sandy loam, dark grayish brown (2.5Y4/2) when moist; soft when dry, very friable when moist, nonsticky and nonplastic when wet; calcareous; clear wavy boundary.
>
> C6-89-130 cm (35.0-51.2 in) (auger sample); light brownish gray (2.5Y6/2) loamy fine sand, dark grayish brown (2.5Y4/2) when moist; soft when dry, loose when moist, nonsticky and nonplastic when wet; slightly calcareous.

CLIMATE

Located in the northern High Plains, Dickinson has a semiarid, continental climate. Winters are cold and snowy, while the summers have warm, sunny days and cool nights. These factors produce cold and somewhat snowy winters in which cold waves and blizzards may be expected. Hot, humid conditions are very rare.

The annual precipitation at Dickinson is 39.4 cm (15.5 in). Precipitation has ranged from less than 17.8 cm (7 in) to more than 78.7 cm (31 in). There are a number of months in the record of no measurable precipitation; these occurred in the period from November to February. More than 75 percent of the annual precipitation falls in the growing season, April through September, while the months of November through February account for just 12 percent of the annual amount.

The annual snowfall has varied from 30.5 cm (12 in) to 188 cm (74 in). Between 68 and 69 cm (27 in) of snow is the greatest monthly total on record. The greatest snowfall for a single day was 35.6 cm (14 in). The snowfall season is October through April.

The winters in Dickinson are moderately cold, with a mean temperature for the winter months, December through February, of -10.1° C (13.8° F). Minimum temperatures drop to -17.8 ° C (0° F) on an average of 46 times each year.

The average temperature for the three summer months, June through August, is 18.7° C (65.7° F). Temperatures of 32.2° C (90° F) or higher occur on an average of about 22 days per year.

Annual pan evaporation, as measured in a standard Weather Service pan of 1.2 m (4 ft) diameter at the Dickinson Experiment Station, averages 87.7 cm (34.5 in) during the growing season of April through September (USDA, 1968).

The annual pattern of precipitation and temperature at the Dickinson Experiment Station (a benchmark weather station) is shown in Table 2, and recent climatological data are given in Table 3.

LAND USE

Soils in Stark County are well suited to irrigation because they have good percolation, are deep, and have favorable relief. However, there is only a limited supply of water suitable for irrigation. There are no known underground sources to warrant irrigation from deep wells.

By 1963, approximately 81 ha (200 acres) had been leveled for gravity-type irrigation along the Heart and Green Rivers. Controlled releases of water from E. W. Patterson Lake provide a dependable supply of water for the areas along the Heart River.

Corn, wheat, barley, oats, and hay are the main crops grown in Stark County. Hard red spring wheat is grown on the largest acreage. During years

TABLE 3. RECENT CLIMATOLOGICAL DATA RECORDED AT DICKINSON EXPERIMENT STATION

Month	Average Temp. ° F	Precipitation in Inches	Evaporation in Inches
Jan, 1976	14.6	0.66	
Feb, 1976	28.2	0.07	
Mar, 1976	26.6	0.30	
Apr, 1976	45.0	2.11	
May, 1976	54.0	1.42	8.83
Jun, 1976	63.8	3.74	8.58
Jul, 1976	70.5	0.75	12.13
Aug, 1976	70.5	0.40	12.00
Sep, 1976	59.7	1.77	8.30
Oct, 1976	40.4	0.65	
Nov, 1976	25.3	0.14	
Dec, 1976	17.4	0.67	
Total, 1976	43.0	12.68	49.84
Jan, 1977	1.4	0.44	
Feb, 1977	25.4	0.36	
Mar, 1977	33.6	1.31	
Apr, 1977	47.5	0.13	3.69
May, 1977	61.7	2.60	9.74
Jun, 1977	65.2	5.38	8.39
Total, Jan-Jun, 1977	39.1	10.22	21.82

Source: National Oceanic and Atmospheric Administration Climatological Data Monthly Summaries.

of normal or above-normal rainfall, two cuttings of hay are harvested. Native grass is usually cut only once every two years unless the areas where it grows receive additional moisture from runoff, a high water table, or water spreading. In areas having sufficient moisture to facilitate crop growth, the hay is cut once each year.

Cattle are raised on most farms in the county and are grazed from seven to nine months each year. Several large dairy farms are located near Dickinson.

Some parts of the county are underlain by minerals of economic value. Valuable minerals that lie near the surface are clay shale, used in the manufacture of tile, and lignite coal. It has been estimated that more than 18,100 million metric tons (20,000 million short tons) of lignite coal underlie the county. Some areas have been explored to see whether certain strata of the Golden Valley Formation can be used as a source of alumina, an aluminum oxide mineral.

Agricultural Practices and Productivity

Both sites are irrigated by the strip and border method. The control site irrigation water supply is from the Heart River. The test site water supply is municipal wastewater from a series lagoon treatment system.

The hydraulic loading from irrigation is approximately 80 cm (31.5 in) per year on the control site and about 140 cm (55 in) on the test site. The irrigation season is generally from May through August. The seasonal precipitation is shown in the climatological section of this report (Tables 2 and 3).

Available information about cropping history for both sites for the past 10 years is:

1. Entire period in permanent pasture of Bromegrass
2. Crop yields were 39.2 quintal/ha (3,500 lb/acre) of air dry forage/year
3. Fertilizer history is 4.5 metric tons/ha (2.0 tons/acre) of barnyard manure/year
4. Fertilizer equivalent is:
   nitrogen - 16 kg/ha/yr pounds per acre per year (lb/acre/yr)
   phosphorus - 2 kg/ha/yr (1.8 lb/acre/yr)
   potassium - 9 kg/ha/yr (8 lb/acre/yr)
5. Pesticides have not been used

SECTION 5

PLANT OPERATION AND COSTS

WASTEWATER TREATMENT

Prior to 1939, a septic tank was used for sewage treatment. In 1939, a secondary treatment system consisting of a sludge digester and high-rate trickling filter with chlorination of the final effluent was constructed. Both were located at the southeast corner of Dickinson, and the outfalls were into the Heart River about 3/4 mile upstream from the control site. The conventional secondary treatment system became overloaded and, rather than expand it, the two-cell series lagoon system was constructed in 1957 along with a one-mile outfall line from the secondary treatment plant east to the lagoons.

The test site was intermittently irrigated with Heart River water from the 1940s to 1959 when arrangements were made to irrigate with effluent from the lagoon system.

In 1972, two 7.46 kilowatt (kW) [10 horsepower (hp)] floating aerators were added to each of the cells. The system was expanded in 1977 by adding a mechanical bar screen to the grit chamber, two new 0.5-ha (1.2-acre) aeration cells with 45 kW (60 hp) turbine-type, surface aerators in series in front of the lagoons, and a third lagoon cell with a net liquid area of 23.5 (58 acres). In June, 1977, during the last sampling trip, the third lagoon was being filled, however, the aeration cells were not in use (Figure 12).

The present waste flow is about 43.8 L/s (1 Mgal/d). Much of the treatment plant effluent has been used for irrigation since 1957, with occasional discharges to the Heart River. Proposed irrigation requirements for zero discharge through 1980 are 30.4 ha (75 acres) adjacent to and including the test site and 45.8 ha (113 acres) on the east side of the Heart River across from the test site. The irrigation water is furnished under a contract to the user at no charge.

The net percolation loss for the two original cells has been estimated at 0.32 cm (0.13 in) per day. The system is owned and operated by the City of Dickinson (Cuskelly, 1974).

WASTEWATER CONSTITUENTS

Historical characteristics of influent and effluent as reported by the city of Dickinson are shown in Table 4.

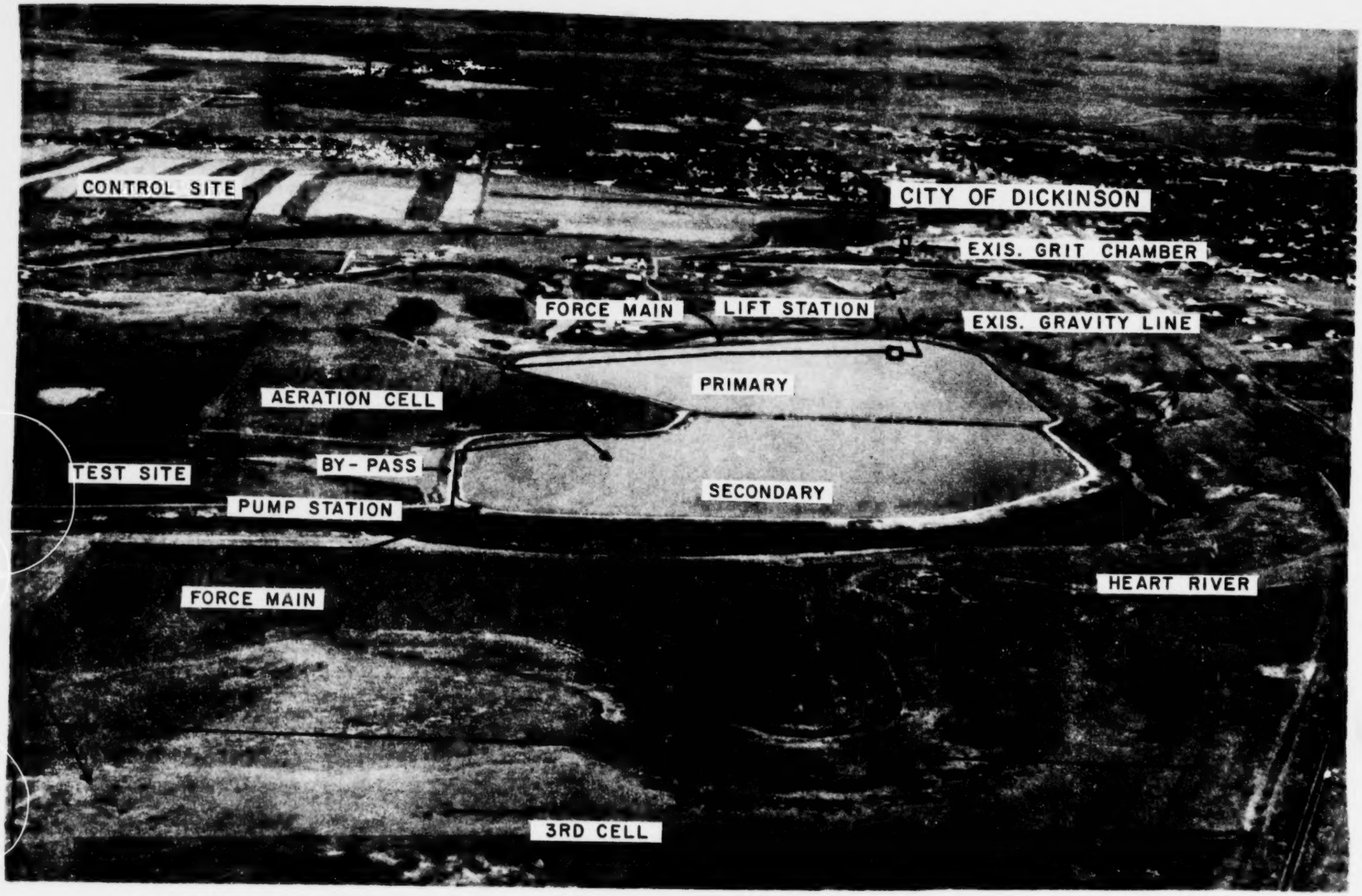

CONTROL SITE
CITY OF DICKINSON
EXIS. GRIT CHAMBER
FORCE MAIN
LIFT STATION
EXIS. GRAVITY LINE
PRIMARY
AERATION CELL
TEST SITE
BY- PASS
SECONDARY
PUMP STATION
HEART RIVER
FORCE MAIN
3RD CELL

Figure 12. Sewage treatment facilities, Dickinson, N.D.

TABLE 4. WASTEWATER CHARACTERISTICS*

	BOD_5 mg/L	Suspended Solids mg/L	Fecal Coliform #/100 mL	Total Phosphorus mg/L	pH
Influent	260	180	-	-	-
Effluent	46	18	9,100	10	7.6

*From City of Dickinson records.

CAPITAL AND OPERATING COSTS

The initial cost of the Dickinson sewage treatment lagoons was about $270,000 in 1957. The 1977 modification cost an estimated $702,000, of which 75 percent was financed by an EPA grant and 25 percent by the City of Dickinson.

The operations and maintenance (O & M) costs for the 1977 fiscal year were:

Maintenance man-hours, including benefits	$ 6,589
Supervisory man-hours, including benefits	1,583
Utilities (including energy cost to operate the irrigation system, bar screens, and lift station)	5,112
Purchased materials	4,929
Total annual O & M	$18,213

This is equivalent to an O & M cost of $0.05/1000 gal.

SECTION 6

RESEARCH METHODS

WELL CONSTRUCTION AND LOCATIONS

Well Construction

The majority of the sampling wells were drilled with a conventional rotary drill rig using Dickinson city water without any bentonite (mud) additive. This was done in order to minimize the introduction of foreign materials to the aquifer zone of interest. The circulation of clear water in the drilling process developed a natural mud, and in the Dickinson area, this natural mud was probably bentonitic. Air rotary drilling was used for 3.6 m (12 ft) of well 22010 (Appendix A), but the hole was completed with water.

Wells were drilled using a large rotary rig with a 10-cm (4-in) bit and then reamed with a 20-cm (8-in) bit. Plastic screens 10 cm (4 in) in diameter and factory slotted with 0.04-cm (0.016-in) slots were placed in the hole with 10-cm (4-in) plastic casing. A cleaned, washed, and screened silica sand from Colorado was placed around and above the screened section. Granular bentonite was slowly poured into the annulus to seal the hole above the screen, and the remainder of the hole was backfilled with native material. The top 15 to 30 cm (6 to 12 in) of the hole was filled with granular bentonite. A summary of well data is given in Table 5.

The PVC casing was cut at about 15 cm (6 in) above the ground surface, and a threaded PVC cap was placed on top of the casing. The area around the casing was filled with either bentonite pellets or powder for a radius of about 30 cm (12 in) and about 13 cm (5 in) deep, and the bentonite was covered with tamped soil. In order to protect the above-ground portion of the casing, a steel pipe, 0.6 m (2 ft) in length and about 25 cm (10 in) in diameter, fitted with a hinged, lockable top, was centered over the top of the casing and pushed about 0.3 m (1 ft) deep into the ground. A typical well completion is shown in Figure 13.

The water-level recorder well, 22140, was completed using 15-cm (6-in) plastic casing and screen. The completion techniques were similar to those already described, except that a large steel box was mounted over the well to protect the well and automatic recorder.

One well was drilled with a small, hand-portable, tripod rotary rig with water as the drilling fluid. A 5-cm (2-in) plastic casing and screen with 0.05-cm (0.020-in) slots was jetted to the desired position with clear water. Several other wells were augered using the tripod rig, and the 5-cm (2-in)

TABLE 5, WELL SUMMARY

WELL NUMBER	TOTAL DEPTH (Ft below G.L.)	SCREEN DEPTH (Ft below G.L.)	PUMPING RATE (G.P.M.)	TOP OF CASING (Ft. above G.L.)	ELEV. TOP OF CASING (m.s.l.) 27 July 76	ELEV. S.W.L. (m.s.l.) 27 July 76	S.W.L. (Ft below T.O.C.) 27 July 76	S.W.L. (Ft below T.O.C.) 9 November 76	S.W.L. (Ft below T.O.C.) 1 April 77	S.W.L. (Ft below T.O.C.) 15 June 77	REMARKS
TEST SITE											
22010	45	37-43	0.1	1.1	2376.04	2361.69	14.35	10.75	13	12.68	Sentinel Butte
22020	23	18-22	15	0.9	2376.06	2367.66	8.4	10.9	12.16	11.13	Alluvium
22030	60	45-50	0.4	0.95	2375.95	2359.53	16.42	15.25	15.46	15.38	Sentinel Butte
22040	30	19-24	0.5	1.0	2373.19	2357.24	15.95	16.39	17.09		Sentinel Butte
22050	17	13-17	1	1.1	2373.13	2357.26	15.37	16.45	17.08	17.1	Alluvium
22060	55	49-55	3	0.6	2372.9	2362.9	10	10.25	10.35	10.1	Sentinel Butte
22070	30	11.5-16.5	0.5		2373.1	2362.93	10.17	11.4	12.9		Alluvium
22080	75	68-74	10	0.83	2373.17	2363.08	10.09	10.3	10.45	9.91	Sentinel Butte
22090	30	13-18	6	0.82	2375.97	2362.41	14.56	15.0	16.23	15.82	Alluvium
22100	20	10-14	10	1.07	2375.55	2370	5.55	7.57	10.34	8.97	Alluvium
22110	26	19-24	3	0.8	2374.44	2357.24	17.2	17.65	19.04	18.56	Alluvium
22120	40	32-37	3	0.6	2384.32	2362.88	21.44	21.66	22.44	22.48	Alluvium
22130	56	49-55	0.2		2384.33	2354.82	29.51	29.39	29.25		Sentinel Butte
22140	23	15-20	30	0.7	2375.51	2367.13	8.38	9.65	---	10.67	Recorder Well Alluvium
22170	12	7-11	10	1.0	2360.92	2355.59	5.33	4.57	---	3.92	Alluvium
22180	23	18-23	30	0.9	2375.97	2367.45	8.52	10.85	12.13	11.1	Alluvium
22190	18.5	16.5-18.5	4	1.0	2374.09	2363.24	10.85	11.45	12.69	12.59	Alluvium
22200	2.5	2.0-2.5	1	1.0	2356.96	2354.26	2.7	2.7	3.14	3.07	Spring Well Alluvium
22210	17	11.5-15.5	--		2374.00		dry	---	---		Alluvium
22220	20	13.5-18.5	--		2373.84	2356.79	17.05	---	---		Alluvium
CONTROL SITE											
21010	60	54-60	10	0.65	2376.97	2366.05	10.92	13.15	14.7		Sentinel Butte
21020	34	29.5-33.5	0.6	0.83	2377	2366.29	10.71	13.05	14.78		Sentinel Butte
21030	20	8-18	25	1.0	2376.6	2368.14	8.46	11.72	14.27	7.39	Alluvium
21040	45	34-44	1.4	0.83	2377.61	2367.06	10.55	13.32	14.98		Sentinel Butte
21050	25	15-20	7	0.6	2377.48	2370.1	7.38	12.59	14.99	10.90	Alluvium
21060	45	39-44	10	0.83	2377.22	2355.26	11.96	13.85	15.92	11.63	Sentinel Butte
21070	27	21-27	2	0.88	2377.23	2365.42	11.81	13.88	15.91	11.53	Sentinel Butte
21080	20	13-18	0.7	0.83	2377.18	2365.38	11.3	13.52	15.37		Sentinel Butte
21090	25	17-25	2.5		2375.88	2367.08	8.3	12.55	---	8.00	Sentinel Butte
21150	30	21-29	1.5	0.85			13				Sentinel Butte
21160	17	6-12	--				14.96				Alluvium

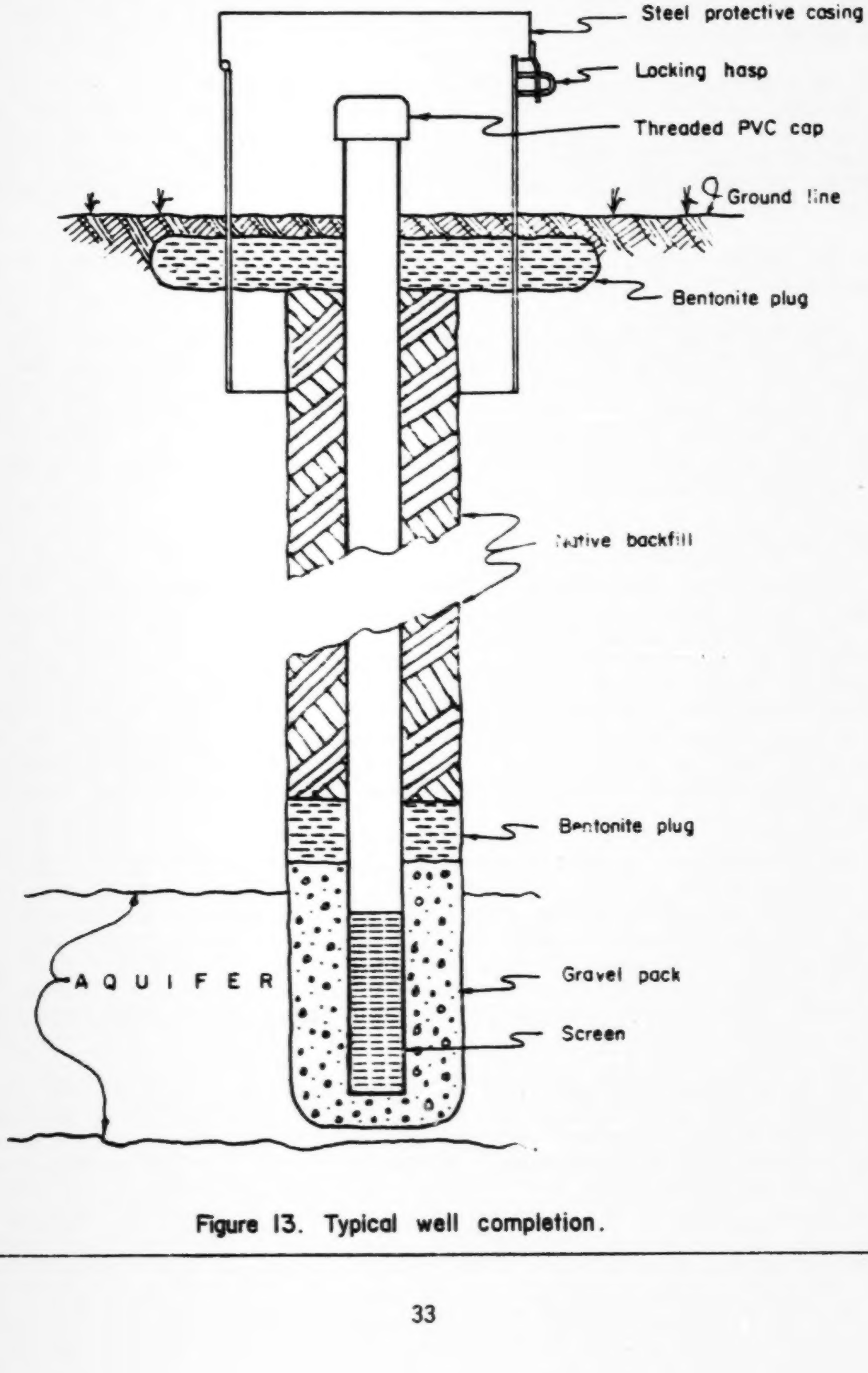

Steel protective casing
Locking hasp
Threaded PVC cap
Ground line
Bentonite plug
Native backfill
Bentonite plug
AQUIFER
Gravel pack
Screen

Figure 13. Typical well completion.

screen and pipe assembly were jetted into place. The surface completion for the 5-cm (2-in) wells was similar to that described above for the 10-cm (4-in) wells.

Well 22200 was constructed at the base of the bluff along the east side of the test site and within an existing spring. Although the well was only 0.8 m (2.5 ft) deep, it sampled water from the gravel layer just at the base of the alluvium. Well 22200 is comparable to well 22220, which could not be sampled, as can be seen by comparing elevations of the top of casing and water levels in Table 5.

All water used for drilling and jetting was treated with Clorox or calcium hypochlorite to contain approximately 350 mg/L chlorine.

The following procedure was used to decontaminate the wells. After completing each sampling well, 76 liters (20 gallons) of 1 percent of calcium hypochlorite solution was poured into the wells. The well was then surged, and the chlorinated water was recirculated by a centrifugal pump to thoroughly wash down the side of the PVC casing. Prior to sampling, the well was pumped and water discarded until the pumped water showed no residual chlorine by the ortho-tolidine test.

Lysimeter Installation

The lysimeter cluster was located on the northern edge of the test site (Figure 4). A hole 10 cm (4 in) in diameter for each of the three lysimeters was drilled with a portable power auger. Prior to installation, each porous lysimeter cup was pretreated by the following procedure: A 300 mL volume of 10 percent Calgon (sodium hexametaphosphate) solution was pulled through each lysimeter cup using a negative pressure of 12.7 cm (5 in) of mercury. This solution was blown out of the lysimeter using a positive pressure. The procedure was repeated once using a 10 percent hydrochloric acid solution and again using distilled water. The pretreated lysimeters were then ready for installation.

Each lysimeter cup was fitted with a specially constructed teflon plastic pipe 30 cm (12 in) in length with a sealed lid capable of holding more than 46 cm (18 in) of negative pressure. Two teflon tubes 0.64 cm (0.25 in) in diameter extended through the lid. One tube connected with the base of the lysimeter and was used to bring the water to the surface. The other tube connected with the top of the lysimeter and was used to apply both negative and positive pressure to blow the water sample out through the lower tube.

A silica flour (crushed silica sand 140 mesh) and distilled water slurry was mixed, and a small portion was poured into the lysimeter hole to keep the base of the cup from contact with the native sediment. The lysimeter assembly was lowered into the hole, and additional silica slurry was poured around the lysimeter to cover the ceramic cup and about 10 cm (4 in) of the teflon body. Material dug from the hole and approximately from the same depth was replaced and lightly tamped. This backfill material was followed by a bentonite plug composed of a very viscous slurry of powdered bentonite and distilled water. The bentonite plug was covered with backfill until the hole was filled. In the case of the two deeper lysimeters, the grass plug was replaced (Figure 14).

Following the installation of the lysimeter assemblies, a negative pressure of 46 cm (18 in) of mercury was placed on each lysimeter. The pasture surrounding the lysimeters was flooded. Samples were blown from the lysimeters three times a day for two and one-half days. The pH was monitored to determine when the system had been purged of the acid treatment. When the pH had stabilized near 7, the lysimeter samples were collected for analysis.

Prior to collection of the July, 1976, lysimeter samples, the test site pasture was flood-irrigated with wastewater, and about 5 cm (2 in) of wastewater covered the lysimeter installation.

SAMPLING

Water Sampling

Water sampling procedures were the same throughout the study. At each sampling point a field recording form was completed to show well number, sample number, time of sample collection, method of sampling, time of well pumping, and pertinent field conditions.

The samples were coded in the following manner for later identification and analyses:

(a) A 24-hour composite of the sewage lagoon effluent was collected and identified as 22460.

(b) A grab sample from the Heart River was collected at the irrigation site and identified as 21460.

(c) Groundwater from the test site was identified as 22010 through 22200, and groundwater from the control site was identified as 21010 through 21150.

(d) Lysimeter samples were identified as 22410, 22420, and 22430.

Wells were sampled by adding approximately 19 L (5 gal) of chlorinated water to the well. The water was circulated through the well and pump for several minutes. Then the well was pumped and the well casing flushed until no residual chlorine was detected by the ortho-tolidine test.

Lysimeters were sampled by blowing each lysimeter clear and applying a vacuum to collect the sample. This procedure was repeated until an adequate volume was collected.

Soil Sampling

An area of approximately 3 ha (5 acres) each at the control and test sites that typically and homogeneously represented the soil type and the crop

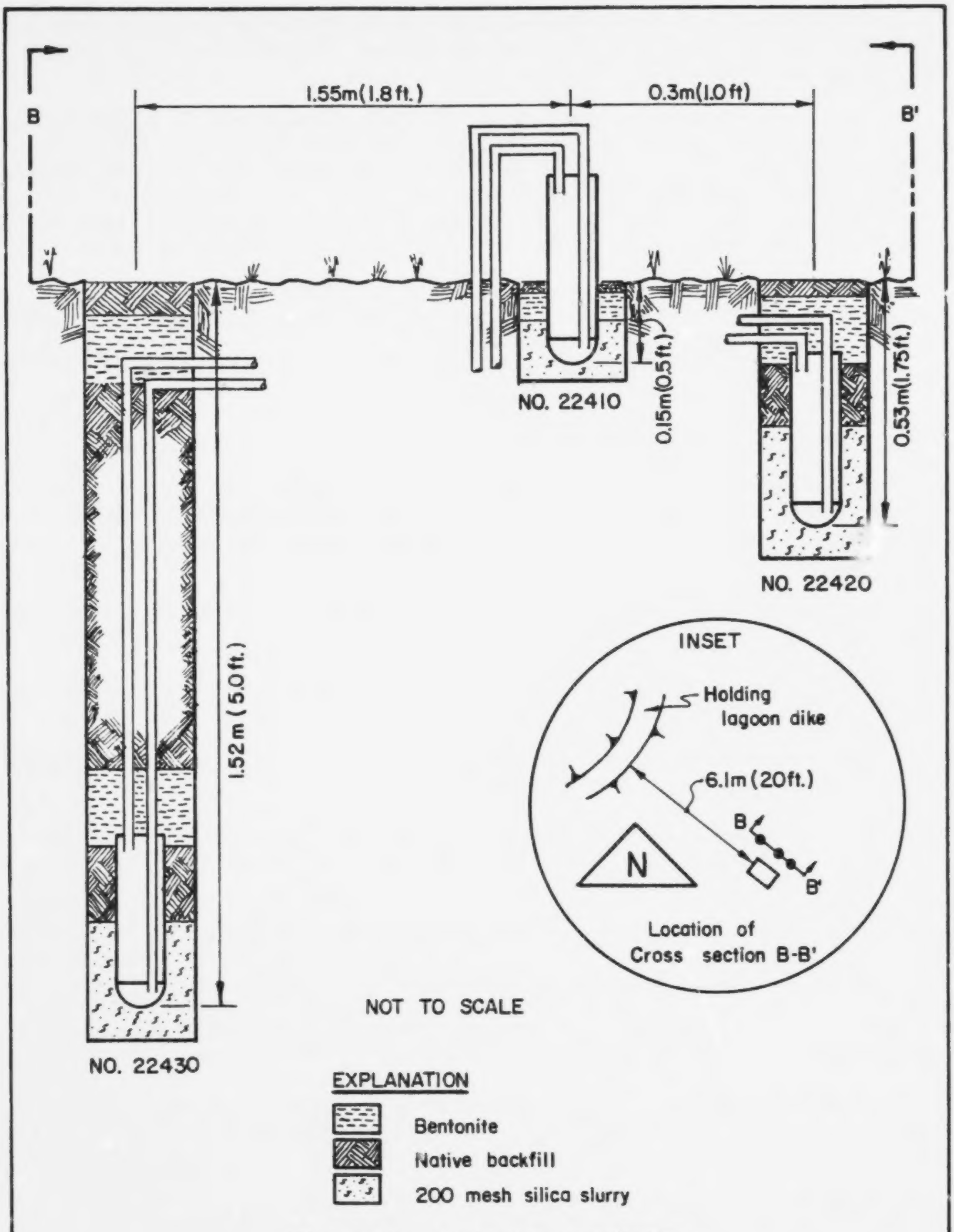

B
B'
1.55m (1.8 ft.)
0.3m (1.0 ft)
NO. 22410
0.15m (0.5 ft.)
0.53m (1.75 ft.)
NO. 22420
1.52 m (5.0 ft.)
NO. 22430
INSET
Holding lagoon dike
6.1m (20ft.)
N
B
B'
Location of Cross section B-B'
NOT TO SCALE
EXPLANATION
Bentonite
Native backfill
200 mesh silica slurry

Figure 14. Lysimeter installation.

being grown was selected for sampling. This selection was coordinated between the agronomist, the groundwater geologist, and the engineer to ensure that the soil, plant, and water samples would be from the same area.

The selected area was subdivided into three approximately equal-sized sub-areas, and each sub-area was used as a sample unit for soil and plant sampling and analysis. Since the area was selected for its homogeneity of soil type and crop condition, the sub-areas were assumed to be representative of conditions for the area as a whole.

Composite soil samples were collected from each sub-area by combining all sub-samples of the same depth. Location of individual sample points within the sub-area followed a random, zigzag pattern. Sample cores were taken from the following depths: 0 to 2 cm (0 to 0.8 in); 2 to 4 cm (0.8 to 1.6 in); 9 to 11 cm (3.5 to 4.3 in); 29 to 31 cm (11 to 12 in); 95 to 105 cm (37 to 41 in); and 205 to 305 cm (81 to 120 in). This sampling regime was followed twice during the study period, once during the warm season (August, 1976) and once during the cool season (November, 1976). Composite soil samples were stored in sealed plastic bags and transported on wet ice to the laboratory.

Plant Sampling

Composite plant samples were collected in a similar manner as for soil samples. The entire above-ground portion of the grass plants was taken for the composite sample. Care was taken to sample only the grass plant, excluding other plants and foreign material.

CHEMICAL AND BIOLOGICAL ANALYSES

Samples collected in the field at the control and test sites were either analyzed at the field laboratory or returned to the laboratory in Oklahoma City, Oklahoma, for analyses. The time-critical parameters were analyzed in the field as soon as the samples were collected. For those samples designated for later laboratory analyses the standard methods for preservation relevant to the parameter to be analyzed were employed. In the following sections the methods used in the analyses of water, soil, and plant samples are presented in sequence. Field methods are discussed prior to laboratory methods. A summary is given in Table 6 of the field method changes that were made during the sampling program to overcome equipment and methodology problems.

Methods for Analyses of Water

Field Analyses--

Alkalinity (total)--Water samples were titrated with a 0.02 N sulfuric acid solution to an end point of pH 4.5. An exactly prepared 0.02 N solution of sodium carbonate was used to standardize the sulfuric acid and was used in spiking water samples (APHA, 1976).

Ammonia--Ammonia analyses were performed with the use of an ammonia electrode. A standard curve was constructed from 1000, 100, 10, 1, and 0.1

TABLE 6. SUMMARY OF FIELD METHODS

Analysis	Sampling Trip			
	Dickinson I	Dickinson II	Dickinson III	Dickinson IV
Alkalinity (Total)	Potentiometric Titration	Potentiometric Titration	Potentiometric Titration	Potentiometric Titration
Ammonia	Probe	Probe	Probe	Probe
BOD	Probe	Probe	Probe	Probe
Chloride	Probe	Probe	Titration	Titration
Coliform (Total)	Membrane Filter	Membrane Filter	Membrane Filter	Membrane Filter
Coliform (Fecal)	Membrane Filter	Membrane Filter	Membrane Filter	Membrane Filter
Conductance	Meter	Meter	Meter	Meter
D.O.	Winkler	Winkler	Winkler	Winkler
Nitrate	Probe	Probe	Cadmium Reduction	Cadmium Reduction
Nitrogen (Kjeldahl)	Digestion & Probe	Digestion & Probe	Digestion & Probe	Digestion & Probe (Modified)
Orthophosphate (Soluble)	Single Reagent	Single Reagent	Single Reagent	Single Reagent
pH	pH Electrode	pH Electrode	pH Electrode	pH Electrode
Phosphorus (Soluble)	Filtration, Digestion, & Single Reagent	Filtration, Digestion, & Single Reagent	Filtration, Digestion, & Single Reagent	Filtration, Digestion, & Single Reagent
Phosphorus (Total)	Digestion & Single Reagent	Digestion & Single Reagent	Digestion & Single Reagent	Digestion & Single Reagent
Sulfide	Probe, No Preservative	Probe, No Preservative	Probe, No Preservative	Probe With Preservative
Sulfate	Probe	Turbidimetric	Turbidimetric	Turbidimetric

mg/L solutions of stock ammonium chloride. The samples and standards were treated identically. The electrode was immersed into the sample, and 10 N sodium hydroxide was added to raise the pH. The millivolt reading was recorded, and the ammonia concentration was determined directly from the calibration curve (Orion IM, 1975a, and Bremner, 1972).

Biochemical oxygen demand--Dissolved oxygen (DO) in water samples was determined with a DO meter prior to setting up biochemical oxygen demands (BOD_5). The meter was air-calibrated with an aneroid barometer according to manufacturer's instructions. Air calibrations were periodically checked against the Winkler method. The samples were diluted with aerated dilution water according to the results obtained from initial experimentation. In some samples no dilutions were required. The initial DO was measured directly in the BOD bottle. The bottles were then carefully glass-stoppered and plastic caps placed over the mouths of the bottles to prevent loss of water from the water seal. The samples were prepared in duplicate and incubated at 20° C in the dark for five days. The final DO was also measured with the probe. Samples containing chlorine were treated with sodium thiosulfate to eliminate the chlorine and then seeded with 24-hour-old domestic wastewater. Glucose-glutamic acid checks were performed to observe the efficiency of the BOD procedures (APHA, 1976).

Coliform (total)--Field samples were collected in sterile glass bottles. Samples were thoroughly mixed, and 1 milliliter (mL) was taken with a sterile pipette and passed through a 0.45 micrometer (μm) Gelman filter. Beginning with sampling rounds three and four, one 50 mL sample was also run. All equipment was sterilized by immersion in boiling water. The filter was aseptically placed on a filter pad containing 2 mL of Endo Broth in a 50 x 12 millimeter (mm) plastic petro dish. The dishes were placed into a whirlpac plastic bag, inverted, and incubated at 35° C for 24 hours in a bacteriological incubator. The typical coliform colonies counted had a pink to dark red color with metallic surface sheen (APHA, 1976).

Coliform (fecal)--The procedure was identical to that for total coliforms with the exception of medium. The medium used was mFC, and plates were not inverted. Plates were incubated at 44.5° C for 24 hours. Typical coliform colonies were small and blue (APHA, 1976).

Conductivity--Determination of specific conductance was performed using a conductivity meter. Using a potassium chloride solution of known conductance, the meter was calibrated prior to running analyses. Specific conductance values were corrected to 25° C by using multiplication factors (APHA, 1971).

Dissolved oxygen--At the well site, immediately after pumping the well, dissolved oxygen was measured by the azide modification of the Winkler method. One Hach powder pillow each of manganous sulfate, alkaline-iodide-azide, and sulfamic acid was added to the water sample. The sample was then brought to the field laboratory and titrated with phenylarsine oxide (PAO) using a starch indicator (APHA, 1976).

Nitrate nitrogen--Samples from rounds one and two were analyzed for nitrate with the use of the nitrate electrode. The probe was immersed in the sample, and the final millivolt reading was recorded. Nitrate concentrations were determined from a standard curve prepared from standards serially diluted from a potassium nitrate stock solution.

Due to the inability to recover spikes and uncontrolled drift in millivolt readings in certain samples, the nitrate probe was replaced with the cadmium reduction column method for sampling rounds three and four. The samples were flocculated and/or filtered through a 0.45 µm Gelman filter prior to analyses. An aliquot of sample was passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. Columns were reactivated between field trips and at other times when efficiency dropped. The nitrite (that originally present plus reduced nitrate) was reacted with the color reagent to form a highly colored azo dye, which was measured spectrophotometrically at 420 nanometers (nm). The nitrite was then determined in the sample and subtracted from the initial value to obtain nitrate (USEPA, 1974; Orion IM, 1975b; and Orion IM, 1976c).

Nitrogen (total and soluble organic)--A micro-Kjeldahl digester and an ammonia electrode were used for analyses. Procedural changes were made throughout the field trips in an attempt to correct the problem of not obtaining total nitrogen recovery. A 50 mL aliquot of sample (filtered for soluble, not filtered for total) was boiled in the presence of concentrated sulfuric acid, potassium sulfate, and mercuric sulfate, and evaporated one-half hour past the disappearance of sulfurous acid fumes. Rounds one, two, and three samples were analyzed by adding 10 N sodium hydroxide to the sample and recording the millivolt reading from the ammonia probe. For the first three rounds, the mercury interference in the digestion reagent was not identified before testing for ammonia. This resulted in an ammonia-mercury complex formation and low nitrogen results. Experiments in the laboratory showed that addition of 2 N sodium iodide with the 10 N sodium hydroxide did not effectively eliminate the mercury interference. Beginning with round four, two major changes were made: 1) Hengar crystals, which are selenium coated, replaced mercury as the catalyst and 2) samples were partially neutralized with sodium hydroxide and allowed to cool in an ice bath prior to ammonia analyses to compensate for heat gained from addition of the sodium hydroxide to acid. Excellent results were obtained, using the final revised procedures (Orion IM, 1975a, and Bremner, 1972).

Orthophosphate (soluble)--Orthophosphate phosphorus was determined by the single reagent method. Samples were filtered through a 0.45 µm Gelman filter. The pH of the sample was adjusted to 7.0 ± 0.2 with sodium hydroxide. Ammonium molybdate, antimony potassium tartrate, and ascorbic acid color reagent were added to the sample and read in the manner described for total phosphorus (USEPA, 1974).

pH--Hydrogen ion concentration (pH) was determined by use of a glass combination pH electrode. The meter was calibrated for pH determinations by using buffers of pH 4, 7, and 10 (APHA, 1976).

Phosphorus (total)--Phosphorus was determined by the single reagent method. Sulfuric acid (11 N) and ammonium persulfate were added to the samples. Samples were boiled gently followed by pH adjustment to pH 7.0 ± 0.2 with sodium hydroxide. Ammonium molybdate, antimony potassium tartrate, and ascorbic acid color reagent were added to the samples. The blue color formed was read at 640 nm using a spectrophotometer. The phosphorus concentration was determined from a standard curve that was prepared from serial dilutions made from a stock phosphorus solution (USEPA, 1974).

Sulfide sulfur--Analyses for sulfide were made with a sulfide electrode. Procedural changes involving sulfide anti-oxidant buffer (SAOB) and standards were a result of additional research by Orion (Orion IM, 1976a).

Rounds one, two, and three samples were brought to the field laboratory, where an aliquot of sample was added to an equal volume of 50 percent SAOB. The SAOB contained sodium hydroxide, sodium salicylate, and ascorbic acid. The calibration curve was prepared from a standard consisting of sodium sulfide, sodium hydroxide, sodium salicylate, and ascorbic acid. The standard was titrated against a 0.1 M lead perchlorate solution to obtain the exact normality. Standards and samples were treated identically except standards were prepared by diluting in 25 percent SAOB. The electrodes were immersed in the sample, and the millivolt reading was recorded after it stabilized. The exact concentration of sulfide was determined from the standard curve (Orion IM, 1975c).

Round four samples were added directly to plastic bottles half filled with 50 percent SAOB in the field. The SAOB contained sodium hydroxide, disodium ethylenediaminetetraacetic acid (EDTA), and ascorbic acid. The calibration curve was prepared from a standard consisting of sodium sulfide and SAOB. The standard was titrated against 0.1 M lead perchlorate to find the exact normality of the standard. This solution was then serially diluted to prepare a standard curve. The samples and standards were treated identically. The electrodes were immersed in the sample, and millivolt readings were recorded. The exact concentration of sulfide was determined from the standard curve (Orion IM, 1976a).

Laboratory Analyses--

Boron--Boron was analyzed by the curcumin method. Samples were added to evaporating dishes made of boron-free glass. Curcumin reagent was added, and the dishes were placed in a water bath set at 55 ± 2° C and evaporated to dryness. The contents of each dish were redissolved in 95 percent ethyl alcohol, filtered through Whatman 30 filter paper, and read at 540 nm on a spectrophotometer. The boron concentration was determined from a standard curve, which was prepared from standards serially diluted from a 100 mg/L boron stock solution (APHA, 1976).

Chemical oxygen demand--Samples were collected in plastic bottles containing sulfuric acid as a preservative and kept on ice until the analyses were completed. The dichromate reflux method was used for chemical oxygen demand (COD) determinations. The alternate procedure for dilute samples in which the potassium dichromate and ferrous ammonium sulfate are more dilute was used for low level COD samples (USEPA, 1974).

Chloride--Analyses for chlorides for the first two rounds were performed with a chloride electrode. During round two, a combination electrode was replaced with a chloride electrode and a double junction reference electrode. Due to problems with these electrodes, sample analyses of rounds three and four were completed by the mercuric nitrate titration method. Hach powder pillows (prepared indicator-acidifier reagent) were used as the indicator for round three, but the indicator-acidifier reagent was used for round four (APHA, 1971).

Prior to running analyses with a chloride electrode, standard curves were prepared from serially diluted standards of a 100 mg/L sodium chloride stock solution. Standards and samples were treated identically. The electrodes were immersed in samples with ionic strength adjuster (ISA) added. Samples were mixed at a constant rate on a magnetic stirrer until stable millivolt readings were observed. Using millivolt readings, unknown concentrations were determined from the calibration curve (Orion IM, 1976b).

Samples for titration were adjusted to a pH of 2.5 with nitric acid, and indicator-acidifier reagent was added to the sample, which was then titrated with 0.0141 N mercuric nitrate. If high chlorides were present, 0.141 N mercuric nitrate was used as the titrant. The samples were titrated to a light purple end point. Iron, which acts as an interference, was removed from the sample through flocculation with zinc sulfate solution and sodium hydroxide. The floc was allowed to settle and was filtered through a 0.45 micron filter. Analyses were performed on the filtrate (APHA, 1976).

Herbicides--Field samples were collected in hexane-rinsed, glass-stoppered bottles. Chlorinated phenoxy acid herbicides were extracted from the acidified water sample with diethyl ether. The ether layer was filtered through anhydrous sodium sulfate into hexane-rinsed bottles, 37 percent potassium hydroxide was added, and the sample was returned to the laboratory for analyses. Water was added to the sample and the ether removed by evaporation. Extraneous organic matter was removed by extracting the basic aqueous phase with diethyl ether. The aqueous phase was acidified to hydrolyze the esters to acids and the acids extracted with diethyl ether. Benzene was added and the solution evaporated to 0.5 mL in Kuderna-Danish evaporators.

The acids were esterified to methyl esters with 0.5 mL boron trifluoride in methanol. The benzene layer was shaken with neutral 5 percent sodium sulfate solution. The benzene extracts were further purified by passing through Florisil columns. Identification and quantification of the esters were made by gas-liquid chromatography and were corroborated through the use of two or more unlike columns (USEPA, 1974).

Metals (total)--Metal analyses were performed by atomic absorption spectrophotometry. Field samples were collected in plastic bottles and preserved with nitric acid to a pH 2. Two bottles were preserved for each sample. Round four samples were filtered at the well site through a 1 μm filter. All metals except for arsenic, selenium, and mercury were prepared by cautiously digesting with nitric acid and evaporating to dryness. Samples were refluxed with nitric acid and brought back to volume, then subjected to the standard conditions and instrumental parameters for the corresponding metals (USEPA, 1974; Martin, 1975; and Atomic Absorption Methods Manual, (1975).

Mercury was analyzed by the cold vapor technique. Concentrated sulfuric acid, concentrated nitric acid, 5 percent potassium permanganate, and potassium persulfate were added, and samples were heated 2 hours at 95° C in a water bath. Sodium chloride and hydroxylamine hydrochloride were added to samples. The mercury was vaporized by adding stannous sulfate (USEPA, 1974).

Arsenic and selenium were determined by atomic absorption, using a heated graphite atomizer and electrodeless discharge lamps. The samples were digested with nitric acid and hydrogen peroxide. Nickel nitrate was added to the digested samples prior to analysis (Martin, 1975).

Organic carbon (total and soluble)--Soluble organic carbon samples were filtered through a 0.45 micron Gelman filter and kept iced until prepared for analyses. Total organic carbon samples were not filtered. Purging and sealing of the ampules were done in the field. Ten mL glass ampules were prepared by adding 0.2 g potassium persulfate to 5 mL of sample and 0.5 mL of 3 percent phosphoric acid. Samples were then purged with oxygen. Phosphoric acid was prepared daily and added to the ampules just prior to sealing. Samples were prepared in triplicate. Carbon dioxide-free water was used for the blanks. Tests were performed in the laboratory to determine optimum length of time for purging and combusting the samples. The organic matter in the ampules was oxidized in a pressure vessel that was placed in an oven heated to 175° C for 16 hours.

After oxidation, the samples were analyzed with a carbon analyzer (USEPA, 1974, and Oceanography International IM, 1971).

Pesticides--Field samples were collected in hexane-rinsed, glass-stoppered bottles. Organochlorine pesticides were extracted from the water with an 85:15, hexane: methylene chloride solvent mixture in the field. The organic layer was filtered through anhydrous sodium sulfate into hexane-rinsed bottles and returned to the laboratory for analysis. The organochlorine pesticides analyzed were endrin, lindane, methoxychlor, and toxaphene. Extracted samples were concentrated in Kuderna-Danish evaporators in a hot water bath. The concentrated samples were purified, if necessary, by passing through Florisil columns. Identification and quantification of pesticides were made by gas-liquid chromatography and were corroborated through the use of two or more unlike columns (USEPA, 1971).

Solids (dissolved)--Samples were brought to room temperature, and well-mixed aliquots were passed through Reeve Angel, type 934 AH filters with gentle suction. One hundred mL was transferred quantitatively to pre-weighed evaporating dishes. Samples were evaporated to dryness at 100° C in a water bath and placed in an oven at 180° C for 1½ to 2 hours. Evaporating dishes were weighed again after cooling in a desiccator (USEPA, 1974).

Solids (suspended)--Samples were brought to room temperature and mixed thoroughly. Using gentle suction, 50 mL of sample was filtered through Reeve Angel, type 934 AH filters in 25 mL tared Gooch crucibles. The filtered samples were dried in an oven at 104° C for one to two hours. Crucibles and filters were desiccated until cool and reweighed (USEPA, 1974).

Solids (total)--Data for total solids were obtained by summing the dissolved and suspended solids values.

Solids (volatile suspended)--The solids retained on the filter from the suspended solids analysis were ignited at 550° C in a muffle furnace to determine volatile suspended solids (USEPA, 1974).

Sulfate sulfur--Round one was analyzed for sulfate with a lead specific ion electrode. Samples were diluted 1:1 with methanol. These were titrated with lead perchlorate until the millivolt readings fell within a range established by a blank curve. The exact sulfate concentration was extrapolated from a standard curve plotted on Grans plotting paper (Orion IM, 1975d).

Due to the inability to duplicate sulfate results using other methods, the remaining rounds of sulfates were analyzed turbidimetrically by the barium sulfate method. While the solution was being stirred, conditioning reagent and barium chloride crystals were added. After exactly one minute, the barium sulfate turbidity was read at 420 nm on a spectrophotometer, and the sulfate concentration was calculated from a standard curve prepared from serially diluted standards of a 1,000 mg/L sodium sulfate stock solution (APHA, 1976).

Methods for Analyses of Soils and Plants

Laboratory Analyses--

Since methods were similar for many of the parameters analyzed in soil and plant samples, these are discussed together in this section. In some instances, the method is only described for either soil or plants (such as pH of soil) or, if different, for each (such as pesticides in soil and in plants).

Cation exchange capacity--Air-dried soil samples (<2 mm particle size) and 1 N ammonium acetate were shaken for several minutes and allowed to stand overnight. Sample extracts were filtered through perforated Coors crucibles containing Reeve Angel glass fiber filters using gentle suction. Soil leaching was done with 1 N ammonium acetate, adding small amounts at a time so that leaching took no less than one hour. This was followed by leaching with 95 percent ethanol in small amounts until the leachate gave a negative test for ammonia with Nessler's reagent. The soil was air-dried and weighed. Water was added, and ammonia was measured with an ammonia electrode by immersing into the sample and adding 10 N sodium hydroxide to raise the pH. Ammonia concentration was determined from a standard curve prepared from serially diluted standards of 1,000 mg/L ammonium chloride stock solution. No modifications were made for calcareous soils (Orion IM, 1975a; Busenberg, 1973; and Black, 1965).

Boron--Air-dried soil samples were refluxed with distilled water for 30 minutes. The soil-water suspension was separated by adding 1 N calcium chloride and centrifuging at 2,000 rpm for 10 minutes. The boron concentration of the supernatant was determined by the curcumin method. Plant samples were dry-ashed at 500° C for one hour in platinum crucibles, and the ash was dissolved in hydrochloric acid and water. Boron concentration was determined by the curcumin method (APHA, 1976, and Black, 1965).

Coliform in plants (total and fecal)--Plant samples were shaken by hand for 10 minutes in a sterile glass bottle containing sterile water and glass beads. Samples were then analyzed in triplicate, using 1 mL samples, by the same procedure used for analysis of total and fecal coliforms in water (Black, 1965).

Herbicides (plants)--Plant samples were mixed with 10 percent ethanolic sulfuric acid solution, petroleum ether, and ethyl ether. After centrifugation the extract was passed through anhydrous sodium sulfate. Sodium hydroxide (2 N) was added, followed by centrifugation. The ether fraction contained the esters and was cleaned with Florisil columns. The acids were liberated from the remaining aqueous solution by shaking with chloroform after acidification with sulfuric acid. After passing the chloroform through filter paper, it was evaporated to near dryness. Ether was added, and the remaining traces of chloroform were removed by evaporation. The extract was concentrated and transferred to a micro-KD evaporator. Benzene was added, and the extract was evaporated to 0.5 mL. Esterification was carried out with boron triflouride in methanol as described for herbicides in water. The benzene layer was passed through a micro-column of Florisil. Extracts were analyzed by gas chromatography (Yip, 1964).

Herbicides (soil)--Air-dried soil samples were mixed with water, sulfuric acid, and diethyl ether. After shaking for four hours, the extracts were filtered through anhydrous sodium sulfate. An aliquot of the ether extract was transferred to a separatory funnel and shaken with sodium hydroxide. The aqueous phase was transferred to another separatory funnel, the pH adjusted to 3, and extracted with ether. Mineral oil in hexane was added to the extract and evaporated carefully to 5 mL, employing a 50° C water bath and a Snyder column. The extract was further evaporated to 0.1 mL. The phenoxy acids were esterified using boron trifluoride in methanol, as described for herbicides in water (Woodham, 1971).

Metals (exchangeable and extractable)--Air-dried soil was pulverized by mortar and pestle to pass a 2 mm screen.

Aluminum was extracted with 1 N potassium chloride. The suspension was filtered immediately, and the solids were washed with 1 N potassium chloride (Ellis, 1975). Aluminum was analyzed by atomic absorption.

The ions K, Mg, and Na were exchanged with 1 N ammonium acetate by shaking for five minutes. Extracts were filtered through Whatman No. 40 filter paper and analyzed by atomic absorption (Ellis, 1975).

The metals Fe, Zn, Mn, Cu, Ni, Pb, Cr, and Co were extracted from soils by shaking for two hours with triethanolamine, calcium chloride, and carboxymethylimino bis-ethylenenitrilo-tetraacetic acid (DTPA) (10 mL per 4 g soil), followed by filtering through Whatman No. 42 filter paper (Ellis, 1975). The metals were analyzed by atomic absorption.

Metals (total)--Samples were prepared by digesting soil in teflon beakers with hydrofluoric acid and evaporating the liquid to dryness. This was followed by digesting with a 3:1 hydrochloric: nitric acid mixture (aqua regia) for five minutes and then redissolving any residue in 1:1 hydrochloric acid. Samples were filtered and analyzed by atomic absorption spectrophotometry.

Total mercury analyses were prepared by digesting soils with aqua regia for two minutes in a 95° C water bath, followed by a 5 percent potassium permanganate digestion for 30 minutes. Sodium chloride, hydroxylamine hydrochloride, and distilled water were mixed with the sample and stannous sulfate was added to vaporize the mercury through the absorption cell. Plant samples were also analyzed by this procedure (USEPA, 1974).

Total arsenic and selenium analyses were prepared by refluxing the soil samples two times with nitric acid, followed by digestion with hydrogen peroxide and nitric acid. Nickel nitrate was added to the digested samples prior to analyses by atomic absorption, using the heated graphite atomizer and electrodeless discharge lamps. Plant samples were prepared in a similar manner.

Nitrogen (inorganic)--Because ammonia, nitrate, and nitrite nitrogen readily change form in soil, these parameters were summed to obtain inorganic nitrogen values. Ammonia, nitrate, and nitrite nitrogen were determined by the following methods:

Ammonia nitrogen was determined after extracting air-dried soil with 2 N potassium chloride by shaking on a rotary shaker for two hours. Samples were allowed to sit for 30 minutes before being analyzed for ammonia with an ammonia electrode. The probe was immersed in the sample, followed by the addition of sodium hydroxide to raise the pH. Ammonia concentration was determined from a standard curve prepared from serially diluted standards of a 1,000 mg/L ammonium chloride stock solution. A 1-gram plant sample was analyzed for ammonia nitrogen following this same procedure (Orion, IM, 1975a, and Black, 1965).

For the nitrate and nitrite nitrogen determination, potassium chloride (2 N) was used to extract the ammonia, nitrate, and nitrite from the air-dried soil by shaking together for one hour. The suspension was filtered through Whatman No. 4 filter paper. The pH was adjusted between 11 and 14 with 10 N sodium hydroxide. At least half the volume of the filtrate was evaporated by boiling, to drive off all ammonia nitrogen. After cooling and adjusting the filtrate to the original volume, concentrated sulfuric acid and Devarda's alloy were added. Samples were placed in a 70° C water bath for two hours for reduction of nitrate and nitrite to ammonia. Ammonia concentrations of the solutions were measured with an ammonia electrode after addition of sodium hydroxide. Ammonia concentration was determined from a standard curve prepared from serially diluted standards of a 1,000 mg/L ammonium chloride stock solution. Plant samples were analyzed for nitrate-nitrite nitrogen following this same procedure (Orion IM, 1975b; Orion IM, 1976c; and Black, 1965).

Nitrogen (organic)--Air-dried soil was digested with concentrated sulfuric acid, potassium sulfate, cupric sulfate, and selenium. The solutions were evaporated for 30 minutes past the disappearance of sulfurous acid fumes. Samples were diluted, neutralized with sodium hydroxide, and analyzed with an ammonia electrode. Ammonia concentration was determined from a standard curve prepared from serially diluted standards of a 1,000 mg/L ammonium chloride stock solution. Plant samples were digested in the presence of concentrated sulfuric acid and analyzed for total organic nitrogen following this same procedure (Orion IM, 1975a; Bremner, 1972; and Black, 1965).

Pesticides (plants)--Plant samples mixed with Celite were extracted with acetonitrile and filtered with vacuum. An aliquot of filtrate was shaken with petroleum ether. Water saturated with sodium chloride was mixed with the ether. The aqueous phase was discarded, and the ether phase was washed twice with water. The ether phase was dried with anhydrous sodium sulfate. Samples were analyzed by gas chromatography (Mills, 1963).

Pesticides (soil)--Soil samples were air-dried, mixed with Celite, and Soxhlet extracted for 12 hours with hexane: acetone (41:59 v/v). The extracts were then shaken in a separatory funnel with a saturated sodium chloride solution and extracted with hexane. The extracts were washed twice with a saturated sodium chloride solution. The hexane phase was dried with anhydrous sodium sulfate. Unless further purification was necessary, the samples were ready for gas chromatographic analyses (Williams, 1968).

pH--The soil was air-dried and pulverized by mortar and pestle before samples were analyzed. Twenty-five mL of distilled water per gram of soil was added and the mixture stirred. The hydrogen ion concentration (pH) was measured while the sample was mixing (Black, 1965).

Phosphorus (available)--Samples of air-dried soil were extracted with 0.03 N ammonium fluoride and 0.025 N hydrochloric acid by shaking for one minute. The extract was filtered through Whatman No. 42 filter paper and the pH adjusted to 7.0 ± 0.2 with sodium hydroxide. Color reagent (mixture of antimony potassium tartrate, ammonium molybdate, and ascorbic acid) was added, and the absorbance was read at 640 nm with a spectrophotometer (APHA, 1976, and Black, 1965).

Phosphorus (total)--Air-dried soil samples were digested with 6 percent perchloric acid in a flask. Samples were boiled until the dark color due to organic matter disappeared. An aliquot was adjusted to pH 7.0 ± 0.2 with sodium hydroxide, followed by the addition of color reagent. After color development, absorbance was measured on a spectrophotometer at 640 nm. Plant samples were digested in the presence of concentrated sulfuric acid and analyzed for total phosphorus following this same procedure (APHA, 1976, and Black, 1965).

Sulfur (total)--The presence of large amounts of sulfur in Dickinson soils made it very difficult to separate sulfate sulfur and organic sulfur; thus the two were combined to obtain total sulfur values.

For the determination of sulfate sulfur, monobasic calcium phosphate was added to air-dried soil samples and shaken for 12 hours, followed by filtering through a Gooch crucible fitted with a glass fiber filter. An aliquot of filtrate, gum acacia solution, and hydrochloric acid was mixed with barium chloride crystals. Absorbance was measured at 420 nm on a spectrophotometer. The concentration of sulfur in the samples was determined from a standard curve prepared from serially diluted standards of a stock sulfate solution. This procedure was also used to analyze sulfate sulfur in plant samples (Black, 1965).

The residue in the Gooch crucible from the sulfate sulfur determination was used for organic sulfur analyses. After drying at 103° C, sodium bicarbonate was mixed with the soil and added uniformly as a surface layer. After ignition at 500° C for three hours the sample was extracted and analyzed as described for sulfate sulfur (Black, 1965).

Methodology Problems and Modifications

As indicated previously, certain difficulties in analyses were experienced in using the standard methods. The following sections discuss the problems encountered in the water, soil, and plant analyses and indicate the modifications that were employed in an attempt to obtain measurements of the parameters involved in the study. Table 6 summarized the modifications for field methods for each of the sampling rounds during the study.

The problems and modifications are mentioned for two reasons. First, for time-critical parameters, it may be the explanation for missing data for certain samples. If the method was known to be faulty, the data were deleted from the data tabulation shown in Appendix B. Second, certain analytical procedures were modified to obtain accurate results for the types of samples encountered in this study. These modifications are reported for the benefit of future investigators for similar type studies. Also, it was deemed valuable to report those cases when certain new analytical tools did not conform to the manufacturer's claims.

Water Analyses--

Calcium--Initial review of calcium data indicated low values were being generated. Spiked samples indicated low recoveries. Therefore, all samples were repeated and were run by the method of standard addition. Excellent recoveries were obtained; therefore, all calcium data are valid.

Chemical oxygen demand--Results from some of the early field samples stimulated questions concerning the procedure being used. Extensive spiking and duplication of samples showed no methodology problems and no reason for the anomalous data.

Chloride--The initial problem was a faulty electrode. Later problems involved matrix interferences. The probe method was replaced by mercuric nitrate titrations as listed in the EPA methods manual (USEPA, 1974).

Metals--Data from several metals appeared anomalous at some time during the analyses. A malfunctioning atomic absorption (AA) was initially a problem. Failures included several faulty hollow cathode lamps, a faulty printed circuit board in the photomultiplier, an out-of-tolerance nebulizer, and numerous graphite rods (cuvettes) that had been manufactured without meeting specifications. Analyses in question were repeated, using an operational instrument. All metal analyses reported are considered valid data.

Nitrate nitrogen--The nitrate probe was used according to the manufacturer's directions with success for some samples, but problems were encountered with other samples. Discussions with the manufacturer resulted in new filling solutions for the probe and different ionic strength adjuster solutions to aid in reducing interferences. Some faulty probes were also discovered during the analyses. Although the probe method was abandoned during round two sampling, nitrate values obtained by the probe were comparable to Cd reduction method values, and data were thus considered valid.

Organic nitrogen--The EPA method was modified initially by using the ammonia probe instead of distilling the ammonia and titrating. It was discovered later that the temperature of the solutions measured with the electrode varied markedly, depending on the amount of acid in the solutions. This temperature variation affected the probe adversely; thus, it was found necessary to partially neutralize samples to about pH 5, cool to room temperature, then add the remainder of the base and measure the ammonia with the probe. Several items concealed this problem initially. Three electrode failures were experienced, and thus questionable data were attributed to this. It was also discovered that mercuric ions in the digesting reagent were not releasing the ammonium during analyses.

Sulfate sulfur--The sulfate (lead) probe was used according to the manufacturer's directions with little success at the sampling sites, although initial tests proved the method satisfactory. Discussions with the manufacturer resulted in numerous changes in the solutions used during analyses. The probe was later found to be faulty as well. The probe was abandoned, and only turbidimetric measurements were used for remaining samples.

Soil and Plant Analyses--

Inorganic nitrogen--Nitrate + nitrite nitrogen was determined initially according to the ASOA method, with the exception that steam distillation of ammonia was replaced by the use of the ammonia probe. Spiked samples indicated that reduction of nitrate and nitrite was limited and that the method was underestimating the concentrations of nitrate and nitrite nitrogen. After much experimentation, it was discovered that the Devarda alloy would not reduce NO_3 and NO_2 to NH_4 without the addition of a proton donor. Satisfactory results were obtained by adding small amounts (<1 mL) of concentrated H_2SO_4.

Organic nitrogen (total)--The method as described by Bremner and Tabatabai (1972) was followed initially. The temperature interference described for the organic nitrogen procedure for water samples was initially a problem for soil and plant samples. Partial neutralization followed by cooling solved the difficulty of obtaining accurate results.

DATA EVALUATION PLAN

General background data about the site including geology, hydrogeology, soils, climate, and other relevant information have previously been presented.

Data collected at the field site from wells, effluent samples, soils, and crops were transmitted to the laboratory for collation and computer tabulation. Additional analytical procedures at the laboratory provided data on many parameters, which were integrated with field data. Appendix B provides complete data tables for all parameters that had reliable, internally consistent results. In some instances columns of data were combined, such as ammonium and nitrate-nitrite nitrogen, if analytical procedures indicated that individual parameters might overlap.

In the Results and Discussion section the critical resource values of water, soils, and crops are compared for the test and control sites.

The evaluation of the results of water analyses is presented in three parts: effluent, surface runoff, and groundwater. In each part the results are discussed in relation to such site characteristics as hydrology, renovation performance of the soil, or quality of the groundwater. In addition, some projections are attempted for long-term loadings of critical parameters contained in the wastewater. The groundwater data that differentiated between control and test sites were essentially the following: COD, Cl, soluable organic nitrogen, Mg, K, Na, SO_4, Ca, and heavy metals.

For soils the results that merited discussion include P, N, and selected heavy metals. Although values were obtained for many other parameters, the differences between control and test sites were generally within the range of variability expected for any one soil site. The soil data that differentiated between control and test sites as a function of depth below surface were the following: Cr, Cu, Zn, Mn, and total P. For the grass crop the parameters for which the data differentiated the control and test sites were the following: Cr, Mn, Na, and Zn.

Finally, the possible adverse health effects associated with fecal and total coliform bacteria were investigated in water and crop samples. Discussion of the methods used and the results obtained for these health-effects parameters follow in the sections on water and crops.

SECTION 7

RESULTS AND DISCUSSION

Samples collected in the field were identified by a code number that was used on all data tables and graphs as well as in the narrative sections where individual sample results are discussed. Water samples had a six-digit number and were coded as follows: The first digit (2) referred to the Dickinson site; the second digit indicated whether sample was from a control (1) or test (2) site; the third and fourth digits indicated the sample number--01 to 40 were taken from wells, 41 to 43 were taken from lysimeters, 46 was irrigation water, and 60 was Dickinson potable water from Patterson Lake. The fifth digit indicated a single or multiple completion well. A zero indicated a single well; and for multiple wells 1 was for shallow, 2 for mid-depth, and 3 for deep wells. The sixth digit indicated the sampling round: 1, first; 2, second; 3, third; and 4, fourth. Dates for sampling rounds are given in the tables.

Soil samples were similarly coded except that only five digits were used. The first and second digits were the same as for water samples. The third digit indicated the sub-area of the control or test site (Figures 4 and 5). The fourth digit indicated the sampling round. The fifth digit indicated the relative sample depth: 1 was 0 to 2 cm, 2 was 2 to 4 cm, 3 was 9 to 11 cm, 4 was 29 to 31 cm, 5 was 95 to 105 cm, and 6 was 295 to 305 cm.

Plant samples were identified with four-digit numbers and followed the same format as soils except that the fifth digit was not used.

WATER

The mean concentrations for the various parameters analyzed in the effluent and river irrigation waters are shown in Table 7. The mean values for the test site represent values from five effluent samples taken during the study. The values for the control site were from only one sample of river water taken during the study.

For purposes of the evaluation, analytical data determined below the limit of detection were arbitrarily input at one-half the detection limit to obtain a mean value. Detection limits for some parameters also changed between rounds and the higher limits are shown in Table 7.

A valid statistical comparison between the mean concentrations for the various parameters at the test and control sites was not possible, since only one sample of the control site irrigation water was available. However, the mean values in Table 7 formed the basis for further analysis, assuming that

TABLE 7. SUMMARY OF CONSTITUENTS DEFINING DIFFERENCES IN APPLIED WATERS

Parameter (mg/L unless noted)	Test Site (Lagoon Effluent)		Control Site (Heart River Water- one sample)	Dickinson Potable Water	
	Range	Mean		Range	Mean
Dissolved Oxygen	<0.1-14.6	9.2	8.3	4.2	4.2
pH (units)	7.6-9.6	8.7	8.8	8.1-9.5	8.8
Conductivity (μmhos/cm)	585-2448	1687	1680	1522-1533	1528
Total Alkalinity	112-404	257	348	136-160	148
Dissolved Solids	392-1726	1202	1119	1022-1081	1052
Suspended Solids	19-247	110	23		
Total Solids	411-1825	1312	1142		
Volatile Suspended Solids	4-135	49	--		
Biochemical Oxygen Demand	24-74	42	7	1^b	1^b
Chemical Oxygen Demand	105-405	248	60	44-59	52
Chloride	28-107	83	20	15-23	19
Sulfide-S	--	--	--		
Total Coliform (#/100mL)	767-TNTC^c	TNTC	533		
Fecal Coliform (#/100mL)	0-TNTC	TNTC	33		
Total Organic C	22-167	93	23		
Dissolved Organic C	3.5-101.6	38.2	18.0	11.7	11.7
Total Organic N	<0.1-9.4	3.4	1.3		
Soluble Organic N	<0.1-11.4	3.7	0.1	0.3-0.8	0.6
Ammonium-N	1.3-13.9	6.9	0.1	<0.1-0.2	0.1
Nitrate-N	<0.1-3.6	1.5	4.0	0.4-1.0	0.7
Total Phosphorus	3.0-10.2	6.90	0.05		
Soluble Phosphorus	0.5-8.5	4.8	0.03	0.4	0.4
Soluble Orthophosphate	0.3-7.5	3.8	0.01^b	0.2	0.2
Sulfate	116-853	359	--	580-606	593
Aluminum	0.3^b-0.8	0.5	0.3^b	0.3^b	0.3^b
Arsenic (μg/L)	5^b-11	6.5	5^b	5^b-12	8
Boron (μg/L)	160-2724	921	250	346-527	437
Cadmium (μg/L)	10^b	10^b	10^b	10^b	10^b

(Continued)

TABLE 7. Continued

Parameter (mg/L unless noted)	Test Site (Lagoon Effluent)		Control Site (Heart River Water- one sample)	Dickinson Potable Water	
	Range	Mean		Range	Mean
Calcium	8-123	55	55	39-50	45
Cobalt (μg/L)	20^b	20^b	20^b	20^b	20^b
Chromium (μg/L)	20^b	20^b	20^b	20^b	20^b
Copper (μg/L)	20^b	20^b	20^b	20^b	20^b
Iron	0.2-1.1	0.7	0.1^b	0.1^b	0.1^b
Lead (μg/L)	100^b	100^b	100^b	100^b	100^b
Magnesium	3-22	15	30	7-11	9
Manganese	0.05^b-0.09	0.05^b	0.23	0.05^b	0.05^b
Mercury (μg/L)	1.0^b	1.0^b	1.0^b	1.0^b	1.0^b
Nickel (μg/L)	50^b-64	50^b	50^b	50^b-97	74
Potassium	2.5-4.1	24	12.4	8.5-9.8	9.2
Sodium	56-491	306	309	309-314	312
Zinc (μg/L)	17-125	50^b	50^b	<20-39	30
Selenium (μg/L)	<10-13	7	5	7-10	8
Endrin (ng/L)	0.03^b	0.03^b	0.03^b	0.03^b	0.03^b
Lindane (ng/L)	8.3-1690	397	2^b	1.5^b-3.8	2.7
Methoxychlor (ng/L)	0.01^b	0.01^b	0.01^b	0.01^b	0.01^b
Toxaphene (ng/L)	0.1^b	0.1^b	0.1^b	0.1^b	0.1^b
2,4-D (ng/L)	1.4^b-80	17	2.7	8.4^b-10.4	9.4
2,4,5 TP Silvex (ng/L)	0.2-354	93	0.2^b	31.4-86.3	58.9

[b] Concentrations below detection limit indicated.

[c] At least one sample analyzed too numerous to count.

the control site sample values were representative of the actual means. With this assumption, 12 parameters were present in significantly higher concentrations in the effluent used for irrigation of the test site than in the river water used for irrigation of the control site: BOD, COD, chloride, total coliform, fecal coliform, total organic nitrogen, soluble organic nitrogen, ammonia, total phosphorus, soluble phosphorus, soluble orthophosphate, and pottassium. Three parameters--nitrate, magnesium, and manganese--were present in higher concentrations in the river water than in the effluent irrigation water.

Table 7 also shows mean concentrations of the chemical and biological parameters in the Dickinson potable water.

Effluent Constituents

Throughout the monitoring period of this study and for the previous 20 years the Dickinson Sewage Treatment Plant operated primarily as a facultative lagoon system. Little aeration was introduced by the new, supplemental aerated lagoons until the summer of 1977, following the last sampling for this study. The resulting effluent was highly variable in the parameters that measure the quality of a wastewater effluent. This was not unusual, considering that the processes existing in a lagoon treatment system are difficult to control. The primary contributors to varying treatment performance are accumulating and decomposing settled solids, climatic cycles, and varying algae and aquatic plant growth and die-off.

Effluent samples 224601 through 224605 were taken from the second lagoon in July and November, 1976, and in April and June, 1977. Five-day biochemical oxygen demand (BOD_5) concentrations ranged from 53 to 74 mg/L in July and June and from 24 to 28 mg/L during November and April. Suspended solids (SS) concentrations ranged from 172 to 247 mg/L in June and July and from 19 to 46 mg/L in April and November. The seasonal differences were attributed to the higher algae populations present in the summer. This was supported by the high dissolved oxygen concentrations, which accompany the daytime behavior of algal blooms, observed during the summer months.

The chemical oxygen demand (COD) concentration varied from 405 mg/L in July, 1976, to 105 mg/L in April, 1977. The high ratio of COD to BOD concentrations of 8 or 9 to 1 for July and November, 1976, decreased to the more normal 4 to 1 for April and June, 1977. This variation was attributed to the changing algal populations plus a relatively warm and anaerobically decaying benthic layer in July and November, 1976. Apparently the decaying benthic layer contributed to lagoon COD through addition of constituents which were resistent to biodegradation as measured by the BOD test.

COD generation was retarded in the benthic layer during the periods of April and June, 1977, allowing the aerobic lagoon processes to metabolize residual COD constituents and to reduce the COD to BOD ratio to the more conventional range of 4 to 1. It is likely that this cycle has been repeated each year of the existence of the facultative lagoon system.

The ammonium nitrogen concentration varied between the extremes of 1.3

mg/L in July, 1976, to 14.0 mg/L in November, 1976. The low concentration in July was attributed to a period of greater nitrification activity in the lagoons corresponding to higher water temperatures. The nitrate nitrogen concentrations ranged from <0.1 to 3.6 mg/L, with the highest concentration corresponding to the July period of higher nitrification activity. Soluble and total organic nitrogen concentrations were variable, with total organic nitrogen ranging from <0.1 mg/L to 9.4 mg/L. The highest concentration of 9.4 mg/L was observed in June, 1977, and may have been caused by an algal bloom. Total nitrogen concentration in the lagoon effluent varied between 5.6 mg/L and 18.6 mg/L. This variation in total nitrogen could not be attributed to seasonal variations alone but likely also included sedimentation of dead algal cells to the lagoon benthic layer plus the varying effects of denitrification that were probably occurring at the edge of and within the anaerobic zone of the lagoons.

Total phosphorus concentrations ranged from 3.0 to 10.2 mg/L. The lowest concentration was observed during July, 1976, at a time when spring and summer algal growth would have had its maximum phosphorus uptake. The soluble phosphorus level was also lowest at this time at 0.5 mg/L, contrasted with concentrations in the range of 4.3 to 8.5 mg/L observed for the other sampling periods.

The sulfate concentrations of 116 to 853 mg/L reflected the natural anhydrite deposits of the area soils. The low concentrations were attributed to dilution by sustained periods of natural precipitation. Snowmelt, for example, was a contributing cause of the low sulfate concentration of 116 mg/L in the lagoons in April, 1977. Dissolved solids concentrations paralleled sulfate concentrations for the same reason.

The chlorinated hydrocarbons lindane, 2,4-D, and 2,4,5 TP silvex were found in April, 1977, at concentrations higher than were found in other groundwater and irrigation water samples.

Overall observations that could be made concerning the Dickinson Sewage Treatment Plant effluent were: (1) BOD, SS, COD, and nitrogen concentrations were extremely variable with the time of year. BOD and SS were in the range of normal to high, COD was in the high range, and nitrogen was in the low to normal range when compared to the concentrations in a typical secondary effluent. (2) Phosphorus concentrations varied with the time of year but were in a range typical of secondary effluents. (3) Sulfate and dissolved solids concentrations reflected the natural geochemistry associated with the Dickinson surface-water potable supply. (4) Lindane, 2,4-D, and 2,4,5 TP silvex, which were identified in one of the five effluent samplings at above background levels, were well below National Interim Primary Drinking Water Regulation maximum contaminant level (MCL) concentrations of 4,000 ng/L, 100,000 ng/L, and 10,000 ng/L, respectively.

Irrigation and Potable Water

Dickinson Dam is located at the southwest corner of Dickinson on the Heart River. Patterson Lake, located above the dam, is the source of regulated water flow to the Heart River east and south of Dickinson. Water from

Patterson Lake is used as the raw potable supply for Dickinson, and the Heart River water below the dam is used by farmers for irrigation, including the farming operation at the control site for this study.

A sample of Heart River water was taken in July, 1976, near the irrigation pumping station for the control site. At the time of sampling, no water was being released to the river at the dam. Since there were no industrial or municipal sewage outfalls into the river upstream of the point where the control site water was obtained, the water in the river was from leakage at the dam plus groundwater recharge to the riverbed.

The BOD and SS concentrations of 7 and 23 mg/L, respectively, were representative of suspended solid-bearing streams containing natural organics that increased the BOD concentration from a normal 1-3 mg/L to 7 mg/L.

The COD concentration of 60 mg/L was not typical of natural water, which usually contains 6 to 10 mg/L. The high concentration suggested that the suspended solids were organic and contributed to the elevated COD concentration.

The ammonium and soluble organic nitrogen concentrations were low, with both being measured at 0.1 mg/L. Total organic and nitrate nitrogen were 1.3 and 4.0 mg/L, respectively, somewhat above typical concentrations.

Concentrations of all forms of phosphorus were low, with total phosphorus at 0.05 mg/L and soluble phosphorus at 0.03 mg/L. The low phosphorus concentrations suggested that stormwater runoff was a negligible contributing factor to the quality of Heart River water at the time of this sampling.

The dissolved solids concentration of 1,119 mg/L was reasonable for the area geochemistry and was comparable to the dissolved solids concentration in the Dickinson wastewater effluent.

Dickinson potable water samples were taken at taps in November, 1976, and April, 1977, and designated as samples 216002 and 216003. All parameters were in the same range as the Heart River irrigation water, which is consistent with their common origin.

A complete listing of parameters measured in irrigation and potable water is presented in Appendix B.

Groundwater

It will be helpful to review some of the factors affecting groundwater quality at the test and control sites before individual groundwater parameters are discussed. Both the test and control sites are underlain in sequence by an alluvial aquifer and a bedrock aquifer in the Sentinel Butte Formation. At the control site, a hydraulic connection was found to exist between the two aquifers. At the test site, the two aquifers appeared to be without such a connection. As shown in Table 5, depth from ground surface to the top of the saturated zone at the control site ranged from 2 to 4 m (7 to 13 ft), and at the test site it ranged from 1 to 7 m (3 to 23 ft) for the alluvial aquifer and from 3 to 9 m (10 to 30 ft) for the Sentinel Butte aquifer.

The test site has been irrigated with effluent from the Dickinson Sewage Treatment Plant lagoons since 1959. Prior to 1974 there were some approved discharges of lagoon effluent directly to the Heart River. Since 1974 all effluent has been discharged on 46 ha (113 acres) of irrigation land. Though the actual amount of effluent applied to the test site was unknown, an estimate was obtained from the following calculations:

1) 3.8×10^6 L (1 Mgal) per day of sewage influent to the Dickinson lagoon treatment system was equivalent to $1{,}387 \times 10^3$ m^3/yr (1,124 acre-ft/yr) of potential effluent for discharge, i.e.,

$$\frac{3.8 \times 10^6 \text{ L/d} \times 365 \text{ d/yr}}{10^3 \text{ L/m}^3} = 1{,}387 \times 10^3 \text{ m}^3\text{/yr}$$

2) Precipitation contributed to the 34.8-ha (86-acre) area lagoon, at a mean precipitation rate of 39.4 cm (15.5 in) per year, was equivalent to an additional 137×10^3 m^3 (111 acre-ft) of liquid per year, i.e.,

$$\frac{39.4 \text{ cm/yr} \times 34.8 \text{ ha} \times 10^4 \text{ m}^2\text{/ha}}{10^2 \text{ cm/m}} = 137 \times 10^3 \text{ m}^3\text{/yr}$$

3) Evapotranspiration loss from the 34.8-ha area lagoon, at an evapotranspiration rate of 127 cm (50 in) per year from 1976 Dickinson area data, was equivalent to a loss of 442×10^3 m^3 (360 acre-ft) per year, i.e.,

$$\frac{34.8 \text{ ha} \times 127 \text{ cm/yr} \times 10^4 \text{ m}^2\text{/ha}}{10^2 \text{ cm/m}} = 442 \times 10^3 \text{ m}^3\text{/yr}$$

4) Leakage loss through lagoon berm, at a rate of 0.33 cm (0.13 in) per day, according to a local Dickinson engineering firm, was equivalent to 419×10^3 m^3 (340 acre-ft) per year, i.e.,

$$\frac{0.33 \text{ cm/d} \times 365 \text{ d/yr} \times 34.8 \text{ ha} \times 10^4 \text{ m}^2\text{/ha}}{10^2 \text{ cm/m}} = 419 \times 10^3 \text{ m}^3\text{/yr}$$

5) Balance of sewage influent and precipitation remaining for irrigation on the 45.7 ha (113 acre) test site was 663×10^3 m^3 (233×10^5 ft^3), i.e.,

$$1{,}387\ 10^3 \text{ m}^3 + 137 \times 10^3 \text{ m}^3 - 442 \times 10^3 \text{ m}^3 - 419 \times 10^3 \text{ m}^3$$

$$= 663 \times 10^3 \text{ m}^3$$

Thus, 663×10^3 m^3 (233×10^5 ft^3) of effluent was estimated to have been applied to the test site each year. Additional irrigation acreage was introduced recently, bringing the total land available for irrigation to 76 ha (188 acres).

The control site was located adjacent to land to the southwest and northwest that was also irrigated with Heart River water. Groundwater at the control site was isolated from surrounding groundwater because of the location of the control site on a meander of the Heart River. Groundwater flow at the control site was comprised primarily of irrigation water and incident precipitation and proceeded in all directions from the mound accumulated under the irrigated land (Figure 10).

The land adjoining the test site to the west was irrigated with effluent. This affected the quality of groundwater entering the test site from the west. Other effluent-irrigated land was located to the east, on the opposite bank of the Heart River. Groundwater flow at the test site was comprised of leakage from the sewage and irrigation storage lagoons, from incoming groundwater flows, and from irrigation effluent. In the northern section of the test site, the primary component of groundwater flow was lagoon leakage water. Alluvium wells 22170, 22130, 22120, 22090, 22100, 22010, 22020, 22030, and lysimeter sampling points 22410, 22420, and 22430 appeared to be affected by this lagoon leakage. The rate of lagoon leakage was about 0.3 cm (0.1 in) per day, which was equivalent to 30 percent of the daily inflow to the lagoons. In the central and southern sections of the test site, the primary component of groundwater flow was irrigation effluent.

Comparisons of the mean concentrations of various parameters sampled in the groundwater below the test site and control site were made using statistical techniques. These techniques consisted of defining the regions of interest, computing sample parameter means for the regions at the test and control sites, and testing for the existence of significant differences in the means at the 0.05 level using the method of pooled variances. The parts of each site compared are shown schematically in Figure 15.

Table 8 compares the mean concentrations of the various parameters sampled from the alluvium wells beneath the test and control sites. The mean concentrations for COD, chloride, dissolved organic carbon, soluble organic nitrogen, sulfate, calcium, magnesium, potassium, sodium, selenium, total alkalinity, and dissolved solids, as well as conductivity, were found to be significantly greater at the 0.05 level for the test site alluvium wells than for the control site alluvium wells. Of the above-mentioned parameters, COD, chloride, soluble organic nitrogen, and potassium were previously noted to occur in greater concentration in the effluent used on the test site. The presence of these parameters in the alluvium well water suggested the leaching of these constituents. In contrast, coliform and phosphorus showed no significant difference at the 0.05 level in the alluvium wells, thus indicating complete removal of these parameters by the land application system.

A comparison (to be discussed later in this section) of the sulfate, calcium, sodium, alkalinity, and dissolved solids concentrations and the conductivity in the test site alluvium wells and the irrigation water suggested that in the alluvium wells the significant differences found for these parameters resulted from natural differences in groundwater quality. It was also

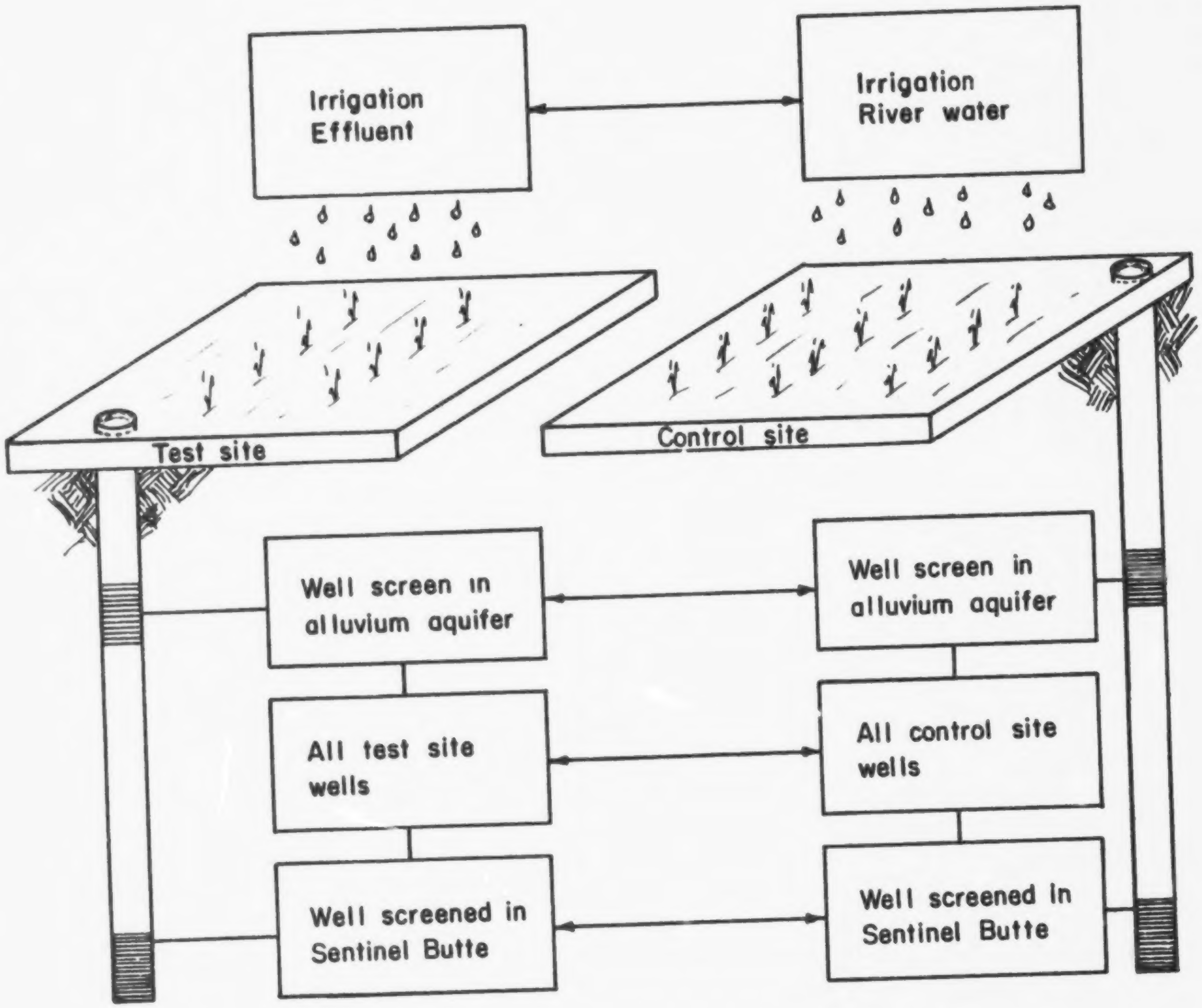

Irrigation
Effluent
Irrigation
River water
Test site
Control site
Well screen in alluvium aquifer
Well screen in alluvium aquifer
All test site wells
All control site wells
Well screened in Sentinel Butte
Well screened in Sentinel Butte

Figure 15. Comparison of the test site and control site.

TABLE 8. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE GROUNDWATERS (WELLS IN ALLUVIUM AQUIFER)

Parameter	Means (mg/L unless noted) Control	 Test
Dissolved Oxygen	3.9	2.6
pH (units)	7.6	7.2[a]
Conductivity (μmhos/cm)	1725	4378[a]
Total Alkalinity	361	558[a]
Dissolved Solids	1214	4750[a]
Biochemical Oxygen Demand	1[b]	1[b]
Chemical Oxygen Demand	19	68[a]
Chloride	32	103[a]
Sulfide-S	--	--
Total Coliform (#/100 mL)	1	12
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	10.8	34.4[a]
Soluble Organic N	0.6	1.3[a]
Ammonium-N	0.3	0.3
Nitrate-N	1.0	2.3
Soluble Phosphorus	0.04	0.05
Soluble Orthophosphate	0.02	0.03
Sulfate	590	2663[a]
Aluminum	0.3[b]	0.4
Arsenic (μg/L)	7	14
Boron (μg/L)	380	863
Cadmium (μg/L)	10[b]	10[b]
Calcium	224	477[a]
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	27
Copper (μg/L)	20[b]	23
Iron	0.5	2.0
Lead (μg/L)	100[b]	100[b]
Magnesium	30	58[a]
Manganese	0.2	1.1
Mercury (μg/L)	0.1[b]	0.1[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	6.9	12.5[a]
Sodium	258	516[a]
Zinc (μg/L)	50[b]	137
Selenium (μg/L)	6	22[a]
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	13.1	8.3
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	6.1	9.0
2,4,5 TP Silvex (ng/L)	35.9	34.1

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

noted that for all remaining parameters, including all metals, the mean concentrations showed no significant difference at the 0.05 level.

Comparison of test and control wells in the Sentinel Butte aquifer is shown in Table 9. The analyses indicated significantly greater mean concentrations in the test site well water for ammonia, nitrate, arsenic, manganese, and zinc in addition to the same 13 parameters previously noted for the alluvium wells, except for soluble organic nitrogen and sulfate (compare Table 8 with Table 9).

Table 10 summarizes a comparison of the mean parameter concentrations for all test site wells to all control site wells. The results were the same as in the previous Sentinel Butte comparison. The data in Tables 11 through 14 present the same comparison as that of Table 10 on an individual round basis. The results show conductivity, dissolved solids, COD, and potassium to be the only parameters with differences significantly greater for the test site wells than for the control site wells at the 0.05 level for each sample round.

The next series of analyses evaluated changes in parameter concentrations across the test site areas. The analyses showed the effect of lagoon leakage on water quality at the test site.

The first analysis compared parameter mean concentrations in groundwater for the wells screened in the alluvium on the north side of the test site, toward the lagoon, to means for the alluvium wells on the south side of the test site. The results are shown in Table 15. Conductivity, dissolved solids, COD, sulfate, calcium, and iron were significantly greater in groundwater from the south test site alluvium wells than from the north test site alluvium wells. With the exception of COD, none of the above parameters were found to be appreciably greater in the irrigation effluent than in the control site irrigation water (Table 7). Also, with the exception of iron, all of the above parameters occurred in significantly greater concentrations in the test site alluvium wells than in the control site alluvium wells (Table 8). From these observations, it appeared that the increase in parameter concentrations at the south side resulted from mixing of the natural water with irrigation percolate and lagoon leakage. In contrast, the concentration of manganese increased from south to north in the test site alluvium wells (Table 15).

The preceding analysis was repeated for the test site wells screened in the Sentinel Butte aquifer (Table 16). Significant differences in mean concentrations were found to exist for nine parameters at the 0.05 level. Five parameters--conductivity, dissolved solids, soluble orthophosphate, sodium, and selenium--decreased in concentration from south to north, indicating dilution for these parameters. In contrast, chloride, ammonium, manganese, and zinc increased in concentration from south to north. Chloride and ammonium were identified as parameters likely to be leaching into the groundwater from effluent irrigation and probably from the lagoon.

In a comparison of two alluvium test site wells (22120 and 22170), close to the lagoons and outside the irrigated area, with the alluvium wells on the

TABLE 9. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE GROUNDWATERS (WELLS IN SENTINEL BUTTE AQUIFER)

Parameter	Means (mg/L unless noted)	
	Control	Test
Dissolved Oxygen	2.8	2.9
pH (units)	8.1	7.8[a]
Conductivity (μmhos/cm)	2062	3739[a]
Total Alkalinity	543	700[a]
Dissolved Solids	1376	3302[a]
Biochemical Oxygen Demand	1[b]	2
Chemical Oxygen Demand	19	44[a]
Chloride	18	54[a]
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	665	140
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	10.7	21.7[a]
Soluble Organic N	0.7	1.0
Ammonium-N	0.3	0.5[a]
Nitrate-N	0.2	0.9[a]
Soluble Phosphorus	0.08	0.09
Soluble Orthophosphate	0.06	0.04
Sulfate	515	1684
Aluminum	2.6	0.9
Arsenic (μg/L)	4	13
Boron (μg/L)	660	485
Cadmium (μg/L)	10[b]	10[b]
Calcium	42	186
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	25
Copper (μg/L)	20[b]	52
Iron	2.8	1.5
Lead (μg/L)	100[b]	100[b]
Magnesium	12	38[a]
Manganese	0.1	0.8[a]
Mercury (μg/L)	0.1[b]	0.1[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	5.2	9.9[a]
Sodium	482	733[a]
Zinc (μg/L)	68	294[a]
Selenium (μg/L)	7	20[a]
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	68.3	12.0[a]
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	6.2	8.1
2,4,5 TP Silvex (ng/L)	51.1	33.1

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 10. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE GROUNDWATERS (ALL WELLS)

Parameter	Means (mg/L unless noted) Control	 Test
Dissolved Oxygen	3.1	2.7
pH (units)	8.0	7.4[a]
Conductivity (µmhos/cm)	1972	4137[a]
Total Alkalinity	496	611[a]
Dissolved Solids	1334	4207[a]
Biochemical Oxygen Demand	1[b]	1
Chemical Oxygen Demand	19	59[a]
Chloride	22	85[a]
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	511	59
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	10.7	30.6[a]
Soluble Organic N	0.7	1.2[a]
Ammonium-N	0.3	0.4
Nitrate-N	0.4	1.8[a]
Soluble Phosphorus	0.07	0.06
Soluble Orthophosphate	0.05	0.03
Sulfate	539	2301[a]
Aluminum	2.0	0.6[a]
Arsenic (µg/L)	5	14[a]
Boron (µg/L)	586	715
Cadmium (µg/L)	10[b]	10[b]
Calcium	94	371[a]
Cobalt (µg/L)	20[b]	20[b]
Chromium (µg/L)	20[b]	20[b]
Copper (µg/L)	20[b]	34
Iron	2.2	1.8
Lead (µg/L)	100[b]	100[b]
Magnesium	17	51[a]
Manganese	0.2	1.0[a]
Mercury (µg/L)	0.1[b]	0.1[b]
Nickel (µg/L)	50[b]	50[b]
Potassium	5.6	11.6[a]
Sodium	422	593[a]
Zinc (µg/L)	61	195[a]
Selenium (µg/L)	6	21[a]
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	53.6	9.7[a]
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	6.2	8.7
2,4,5 TP Silvex (ng/L)	47.1	33.7

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 11. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE GROUNDWATERS SAMPLED JULY, 1976

Parameter	Means (mg/L unless noted)	
	Control	Test
Dissolved Oxygen	3.3	3.3
pH (units)	8.0	7.3[a]
Conductivity (μmhos/cm)	1987	4022[a]
Total Alkalinity	535	612
Dissolved Solids	1312	4275[a]
Biochemical Oxygen Demand	1[b]	1
Chemical Oxygen Demand	20	57[a]
Chloride	18	78[a]
Sulfide-S	--	--
Total Coliform (#/100 mL)	0	87
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	8.8	19.6[a]
Soluble Organic N	0.5	0.7
Ammonium-N	0.3	0.3
Nitrate-N	0.6	2.1[a]
Soluble Phosphorus	0.01[b]	0.03
Soluble Orthophosphate	0.01[b]	0.02
Sulfate	474	2329
Aluminum	3.4	1.4
Arsenic (μg/L)	6	20[a]
Boron (μg/L)	176	185
Cadmium (μg/L)	10[b]	10[b]
Calcium	61	362[a]
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	20[b]	25
Iron	2.7	2.4
Lead (μg/L)	100[b]	100[b]
Magnesium	14	60[a]
Manganese	0.1	0.7
Mercury (μg/L)	0.1[b]	0.1[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	6.9	12.9[a]
Sodium	441	624
Zinc (μg/L)	50[b]	50[b]
Selenium (μg/L)	5	28
Endrin (ng/L)	0.02	0.02
Lindane (ng/L)	98.5	15.0
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	1.0[b]	1.0[b]
2,4,5 TP Silvex (ng/L)	0.2[b]	0.2[b]

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 12. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE GROUNDWATERS SAMPLED NOVEMBER, 1976

Parameter	Means (mg/L unless noted) Control	Test
Dissolved Oxygen	2.5	2.4
pH (units)	7.9	7.5[a]
Conductivity (μmhos/cm)	2094	4349
Total Alkalinity	465	603[a]
Dissolved Solids	1397	4153[a]
Biochemical Oxygen Demand	1[b]	1[b]
Chemical Oxygen Demand	18	65[a]
Chloride	14	77[a]
Sulfide-S	--	--
Total Coliform (#/100 mL)	330	94
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	0.1[b]	67.7
Soluble Organic N	1.0	1.7
Ammonium-N	0.3	0.4
Nitrate-N	0.4	2.2[a]
Soluble Phosphorus	0.11	0.11
Soluble Orthophosphate	0.07	0.03
Sulfate	536	2560
Aluminum	2.1	0.3[b]
Arsenic (μg/L)	4	9[a]
Boron (μg/L)	997	1483
Cadmium (μg/L)	20[b]	20[b]
Calcium	61	412[a]
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	20[b]	25
Iron	3.0	1.7
Lead (μg/L)	100[b]	100[b]
Magnesium	22	38
Manganese	0.2	1.0
Mercury (μg/L)	0.1[b]	0.1[b]
Nickel (μg/L)	50[b]	61
Potassium	6.0	11.8[a]
Sodium	456	577
Zinc (μg/L)	88	194
Selenium (μg/L)	8	21[a]
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	2.0[b]	2.0[b]
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	1.0[b]	4.2
2,4,5 TP Silvex (ng/L)	118	80.5

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 13. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE GROUNDWATERS SAMPLED APRIL, 1977

Parameter	Means (mg/L unless noted) Control	 Test
Dissolved Oxygen	3.3	2.5
pH (units)	8.1	7.4[a]
Conductivity (μmhos/cm)	1879	4061[a]
Total Alkalinity	520	598
Dissolved Solids	1318	4330[a]
Biochemical Oxygen Demand	2	2
Chemical Oxygen Demand	23	64[a]
Chloride	20	80[a]
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	5000	36[a]
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	14.5	26.1
Soluble Organic N	0.6	0.7
Ammonium-N	0.2	0.5
Nitrate-N	0.2	1.9
Soluble Phosphorus	0.08	0.05
Soluble Orthophosphate	0.06	0.05
Sulfate	526	2340[a]
Aluminum	0.5	0.5
Arsenic (μg/L)	3	12
Boron (μg/L)	641	719
Cadmium (μg/L)	20[b]	20[b]
Calcium	203	396
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	20[b]	40
Iron	0.8	2.0
Lead (μg/L)	100[b]	100[b]
Magnesium	16	49[a]
Manganese	0.2	1.2
Mercury (μg/L)	0.1[b]	0.1[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	3.8	8.4[a]
Sodium	404	601[a]
Zinc (μg/L)	53	432[a]
Selenium (μg/L)	6	14[a]
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	72.4	11.1
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	16.4	23.8
2,4,5 TP Silvex (ng/L)	32.5	37.0

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 14. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE GROUNDWATERS SAMPLED JUNE, 1977

Parameter	Means (mg/L unless noted)	
	Control	Test
Dissolved Oxygen	3.6	2.4
pH (units)	8.0	7.6
Conductivity (μmhos/cm)	1768	4065[a]
Total Alkalinity	429	637[a]
Dissolved Solids	1265	4042[a]
Biochemical Oxygen Demand	1[b]	1[b]
Chemical Oxygen Demand	16	47[a]
Chloride	57	108
Sulfide-S	--	--
Total Coliform (#/100 mL)	0	8
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	12.8	36.7[a]
Soluble Organic N	0.7	1.9[a]
Ammonium-N	0.3	0.5
Nitrate-N	0.4	0.6
Soluble Phosphorus	0.10	0.06
Soluble Orthophosphate	0.08	0.04
Sulfate	600	1887[a]
Aluminum	0.3[b]	0.3[b]
Arsenic (μg/L)	10	16
Boron (μg/L)	496	632
Cadmium (μg/L)	20[b]	20[b]
Calcium	83	294
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	20[b]	48
Iron	0.2[b]	1.0
Lead (μg/L)	100[b]	100[b]
Magnesium	19	57
Manganese	0.05[b]	1.0
Mercury (μg/L)	0.1[b]	0.1[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	4.4	14[a]
Sodium	318	563
Zinc (μg/L)	34	101
Selenium (μg/L)	5	23
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	43.3	11.8
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1	0.1[b]
2,4-D (ng/L)	8.3	4.7
2,4,5 TP Silvex (ng/L)	8.4	9.9

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 15. MEAN CONCENTRATIONS OF PARAMETERS IN TEST SITE GROUNDWATER (WELLS IN ALLUVIUM AQUIFER)

Parameter	Means (mg/L unless noted) North Side of Test Site	South Side of Test Site
Dissolved Oxygen	2.4	2.6
pH (units)	7.3	7.2
Conductivity (μmhos/cm)	3344	4953[a]
Total Alkalinity	568	552
Dissolved Solids	3345	5506[a]
Biochemical Oxygen Demand	1[b]	1[b]
Chemical Oxygen Demand	54	75[a]
Chloride	107	101
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	1	19
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	24.1	39.8
Soluble Organic N	1.3	1.4
Ammonium-N	0.4	0.3
Nitrate-N	1.5	2.8
Soluble Phosphorus	0.04	0.06
Soluble Orthophosphate	0.03	0.03
Sulfate	1685	3260[a]
Aluminum	0.3[b]	0.5
Arsenic (μg/L)	11	17
Boron (μg/L)	1226	661
Cadmium (μg/L)	20[b]	20[b]
Calcium	246	624[a]
Cobalt (μg/L)	20[b]	23
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	17	27
Iron	1.0	2.7[a]
Lead (μg/L)	100[b]	100[b]
Magnesium	60	57
Manganese	1.8	0.7
Mercury (μg/L)	1.0[b]	1.0[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	12	13
Sodium	497	528
Zinc (μg/L)	74	177
Selenium (μg/L)	18	25
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	5.0	10.3
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	4.7	11.7
2,4,5 TP Silvex (ng/L)	28.3	37.9

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 16. MEAN CONCENTRATIONS OF PARAMETERS IN TEST SITE GROUNDWATER (WELLS IN SENTINEL BUTTE AQUIFER)

Parameter	Means (mg/L unless noted) North Side of Test Site	 South Side of Test Site
Dissolved Oxygen	3.1	2.7
pH (units)	7.6	7.9
Conductivity (μmhos/cm)	3178	4131[a]
Total Alkalinity	633	743
Dissolved Solids	2590	3756[a]
Biochemical Oxygen Demand	3	1
Chemical Oxygen Demand	53	38
Chloride	81	37[a]
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	53	196
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	23.6	20.1
Soluble Organic N	1.2	0.9
Ammonium-N	0.7	0.4[a]
Nitrate-N	0.6	1.1
Soluble Phosphorus	0.06	0.11
Soluble Orthophosphate	0.01[b]	0.07[a]
Sulfate	1234	1999
Aluminum	1.4	0.6
Arsenic (μg/L)	8	16
Boron (μg/L)	491	482
Cadmium (μg/L)	20[b]	20[b]
Calcium	187	186
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	83	32
Iron	2.1	1.1
Lead (μg/L)	100[b]	100[b]
Magnesium	51	28
Manganese	1.8	0.2[a]
Mercury (μg/L)	1.0[b]	1.0[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	10	9.7
Sodium	593	831[a]
Zinc (μg/L)	574	116[a]
Selenium (μg/L)	14	23[a]
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	9.4	13.3
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	4.5	10.3
2,4,5 TP Silvex (ng/L)	43.0	26.8

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

north side of the test site (Table 17), significant differences were observed for 11 parameters. Conductivity, dissolved solids, soluble phosphorus, sulfate, calcium, sodium, and selenium decreased from the north alluvium wells to the wells close to the lagoon, implying a dilution effect by the lagoon leakage. Total alkalinity, ammonium, iron, and manganese increased in concentration from the north alluvium wells to the wells close to the lagoon. This suggested that ammonium was being added to the alluvium while iron and manganese were being leached from the soils as a result of the lagoon leakage.

Table 18 shows a similar analysis for one well in the Sentinel Butte aquifer. This was the only screened well (22130) not affected by irrigation in the test site. Only sulfate showed a significant difference at the 0.05 level, indicating dilution by the lagoon water.

The final statistical analysis was an evaluation of the significance of changes in various concentrations of parameters in the groundwater below the test and control sites as a function of season. The wells at each site were grouped according to aquifer. The method of pooled variances was used in determining whether or not a significant change at the 0.05 level occurred between the various rounds. For each well grouping, an analysis was performed to reveal changes occurring from sampling round one to round two (July, 1976, to November, 1976), round two to round three (November, 1976, to April, 1977), round three to round four (April, 1977, to June, 1977), and round one to round three (July, 1976, to April, 1977). The results of the analyses are summarized in Table 19.

At the test site wells 16 of 49 parameters showed a significant difference in mean values for at least one round-to-round comparison. At the control site wells 19 of 49 parameters were found to have a significant difference at the 0.05 level for at least one round-to-round comparison. The results emphasized the importance of monitoring the wells during all seasons of the year in order to obtain more representative measurements of water quality.

From Table 19, it can also be observed that nitrogen, boron, potassium, lindane, 2,4-D, and 2,4,5 TP silvex varied significantly at the test and control sites. Furthermore, the analysis suggested a direction of a change (increase or decrease) that was consistent and independent of whether the well was at the test site or control site or whether the well was screened in the alluvium aquifer or the Sentinel Butte aquifer. For example, when a significant change in boron concentration did occur, it was in the same direction and independent of aquifer and site.

Nitrogen--

Ammonium nitrogen concentrations ranged from <0.1 to 0.5 mg/L (Figure 16) and <0.1 to 2.8 mg/L (Figure 17) at the control and test sites, respectively Ammonium nitrogen was noticeably higher in concentration in the northerly wells 22100, 22010, 22020, 22030, 22090, 22120, 22130, 22170, and at lysimeter sampling points 22410, 22420, and 22430. All of the above monitoring stations were believed to be within the groundwater area affected by lagoon leakage.

An examination of the remaining wells in the middle to southern area of

TABLE 17. MEAN CONCENTRATIONS OF PARAMETERS OF WELLS IN THE ALLUVIUM AQUIFER NOT AFFECTED BY IRRIGATION IN THE TEST SITE

Parameter	Means (mg/L unless noted) Wells Not Affected by Irrigation	North Side of Test Site
Dissolved Oxygen	1.9	2.2
pH (units)	7.3	7.3
Conductivity (μmhos/cm)	2260	3632[a]
Total Alkalinity	634	569[a]
Dissolved Solids	1671	3718[a]
Biochemical Oxygen Demand	1[b]	1[b]
Chemical Oxygen Demand	47	54
Chloride	101	110
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	0	1
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	28.0	24.6
Soluble Organic N	1.7	1.2
Ammonium-N	1.0	0.4[a]
Nitrate-N	1.1	1.5
Soluble Phosphorus	0.02	0.04[a]
Soluble Orthophosphate	0.02	0.03
Sulfate	604	1836[a]
Aluminum	1.0	0.3[b]
Arsenic (μg/L)	21	15
Boron (μg/L)	344	1118
Cadmium (μg/L)	20[b]	20[b]
Calcium	170	301[a]
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	14	16
Iron	7.1	1.6[a]
Lead (μg/L)	100[b]	100[b]
Magnesium	42	57
Manganese	3.0	1.5[a]
Mercury (μg/L)	1.0[b]	1.0[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	7.7	11.6
Sodium	362	514[a]
Zinc (μg/L)	49	69
Selenium (μg/L)	6	18[a]
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	5.5	6.2
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	2.9	4.6
2,4,5 TP Silvex (ng/L)	47.1	28.6

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 18. MEAN CONCENTRATIONS OF PARAMETERS OF WELLS IN THE SENTINEL BUTTE AQUIFER NOT AFFECTED BY IRRIGATION IN THE TEST SITE

Parameter	Means (mg/L unless noted) Wells Not Affected by Irrigation	North Side of Test Site
Dissolved Oxygen	3.6	3.1
pH (units)	7.9	7.6
Conductivity (μmhos/cm)	2925	3178
Total Alkalinity	708	633
Dissolved Solids	2185	2590
Biochemical Oxygen Demand	2	3
Chemical Oxygen Demand	49	53
Chloride	43	81
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	0	53
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	17.2	23.6
Soluble Organic N	1.5	1.2
Ammonium-N	1.5	0.8
Nitrate-N	1.3	0.6
Soluble Phosphorus	0.07	0.06
Soluble Orthophosphate	0.03	0.01[b]
Sulfate	765	1234[a]
Aluminum	1.7	1.4
Arsenic (μg/L)	32	8
Boron (μg/L)	405	491
Cadmium (μg/L)	20[b]	20[b]
Calcium	78	187
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	61	83
Iron	2.1	2.1
Lead (μg/L)	100[b]	100[b]
Magnesium	23	51
Manganese	1.5	1.8
Mercury (μg/L)	1.0[b]	1.0[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	7.7	10.1
Sodium	673	593
Zinc (μg/L)	326	574
Selenium (μg/L)	14	14
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	30	9.4
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	1.7	4.5
2,4,5 TP Silvex (ng/L)	40	43

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 18. MEAN CONCENTRATIONS OF PARAMETERS OF WELLS IN THE SENTINEL BUTTE AQUIFER NOT AFFECTED BY IRRIGATION IN THE TEST SITE

	Means (mg/L unless noted)	
Parameter	Wells Not Affected by Irrigation	North Side of Test Site
Dissolved Oxygen	3.6	3.1
pH (units)	7.9	7.6
Conductivity (μmhos/cm)	2925	3178
Total Alkalinity	708	633
Dissolved Solids	2185	2590
Biochemical Oxygen Demand	2	3
Chemical Oxygen Demand	49	53
Chloride	43	81
Sulfide-S	0.1[b]	0.1[b]
Total Coliform (#/100 mL)	0	53
Fecal Coliform (#/100 mL)	0	0
Dissolved Organic C	17.2	23.6
Soluble Organic N	1.5	1.2
Ammonium-N	1.5	0.8
Nitrate-N	1.3	0.6
Soluble Phosphorus	0.07	0.06
Soluble Orthophosphate	0.03	0.01[b]
Sulfate	765	1234[a]
Aluminum	1.7	1.4
Arsenic (μg/L)	32	8
Boron (μg/L)	405	491
Cadmium (μg/L)	20[b]	20[b]
Calcium	78	187
Cobalt (μg/L)	20[b]	20[b]
Chromium (μg/L)	20[b]	20[b]
Copper (μg/L)	61	83
Iron	2.1	2.1
Lead (μg/L)	100[b]	100[b]
Magnesium	23	51
Manganese	1.5	1.8
Mercury (μg/L)	1.0[b]	1.0[b]
Nickel (μg/L)	50[b]	50[b]
Potassium	7.7	10.1
Sodium	673	593
Zinc (μg/L)	326	574
Selenium (μg/L)	14	14
Endrin (ng/L)	0.03[b]	0.03[b]
Lindane (ng/L)	30	9.4
Methoxychlor (ng/L)	0.01[b]	0.01[b]
Toxaphene (ng/L)	0.1[b]	0.1[b]
2,4-D (ng/L)	1.7	4.5
2,4,5 TP Silvex (ng/L)	40	43

[a] Test and control sites are significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

TABLE 19. SEASONAL VARIATION OF MEAN CONCENTRATIONS OF PARAMETERS IN GROUNDWATER AT THE TEST AND CONTROL SITES

	Control Site								Test Site							
	Alluvium				Sentinel Butte				Alluvium				Sentinel Butte			
Parameter	R 1 vs. R 2	R 2 vs. R 3	R 3 vs. R 4	R 1 vs. R 3	R 1 vs. R 2	R 2 vs. R 3	R 3 vs. R 4	R 1 vs. R 3	R 1 vs. R 2	R 2 vs. R 3	R 3 vs. R 4	R 1 vs. R 3	R 1 vs. R 2	R 2 vs. R 3	R 3 vs. R 4	R 1 vs. R 3
Dissolved Oxygen																
pH (units)		I							I							
Conductivity (μmhos/cm)																
Total Alkalinity																
Dissolved Solids	I		D	I												
Biochemical Oxygen Demand																
Chemical Oxygen Demand																
Chloride							I				I					
Sulfide-S																
Total Coliform (#/100 mL)						I		I								
Fecal Coliform (#/100 mL)																
Dissolved Organic C								I	I	D	I					
Soluble Organic N	I	D							I							
Ammonium-N								D								
Nitrate-N		D	I											D		D
Soluble Phosphorus					I			I								
Soluble Orthophosphate										I		I				
Sulfate																
Aluminum																D
Arsenic (μg/L)			I		D		I	D								D
Boron (μg/L)	I	D			I	D		I	I			I				I
Cadmium (μg/L)																
Calcium							I									
Cobalt (μg/L)																
Chromium (μg/L)																
Copper (μg/L)																
Iron	I															
Lead (μg/L)																
Magnesium	I		I	I								D				
Manganese																
Mercury (μg/L)																
Nickel (μg/L)																
Potassium				D		D		D			I				I	D
Sodium																
Zinc (μg/L)										I		I				I
Selenium (μg/L)					I									D		D
Endrin (ng/L)																
Lindane (ng/L)					D	I			D	I						
Methoxychlor (ng/L)																
Toxaphene (ng/L)																
2,4-D (ng/L)	I				I			I	I	I	D	I				I
2,4,5 TP Silvex (ng/L)	I	D		I	I			I	I			I		D		I

I - Significant difference at the 0.05 level with an increase in mean concentration.

D - Significant difference at the 0.05 level with decrease in mean concentration.

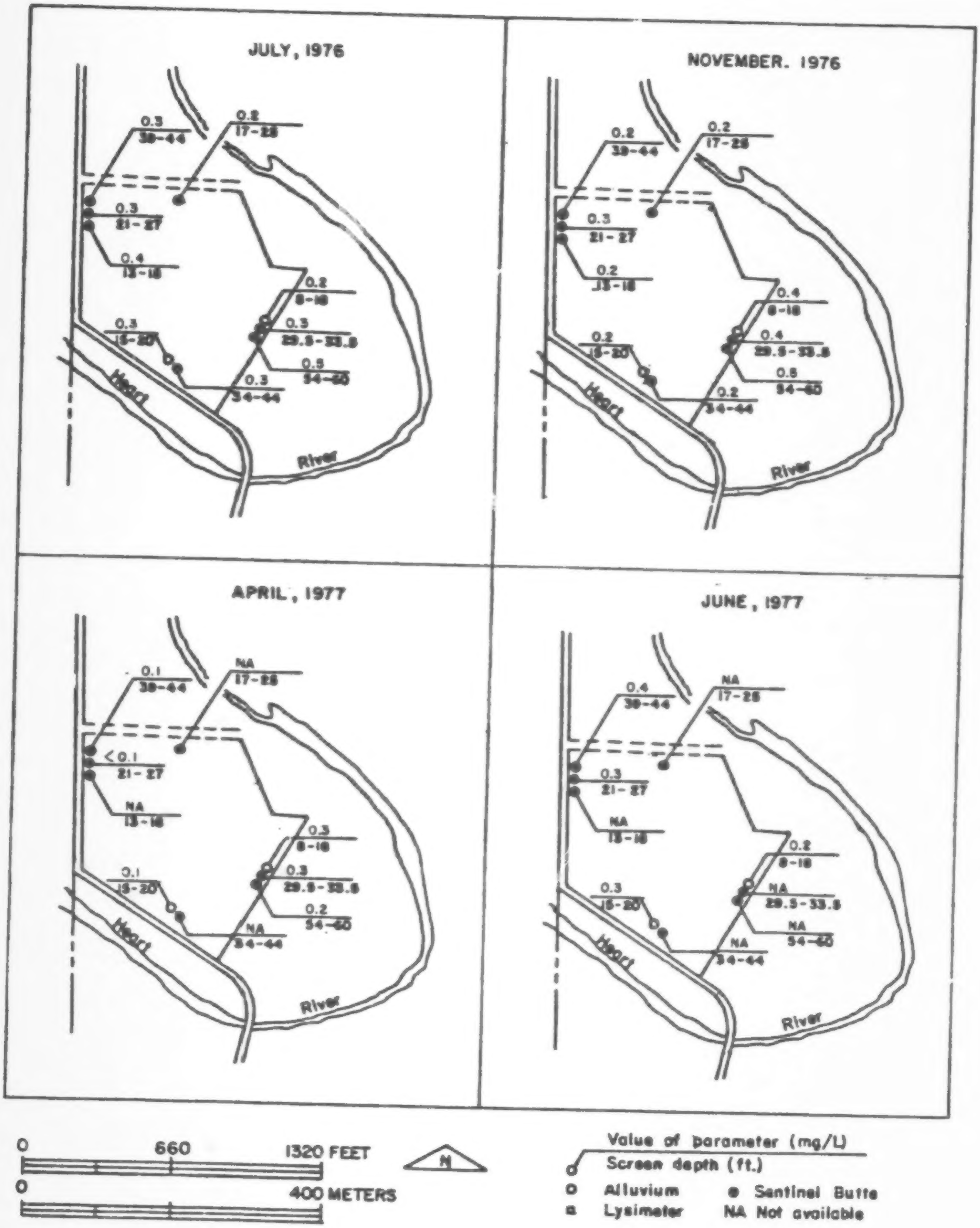
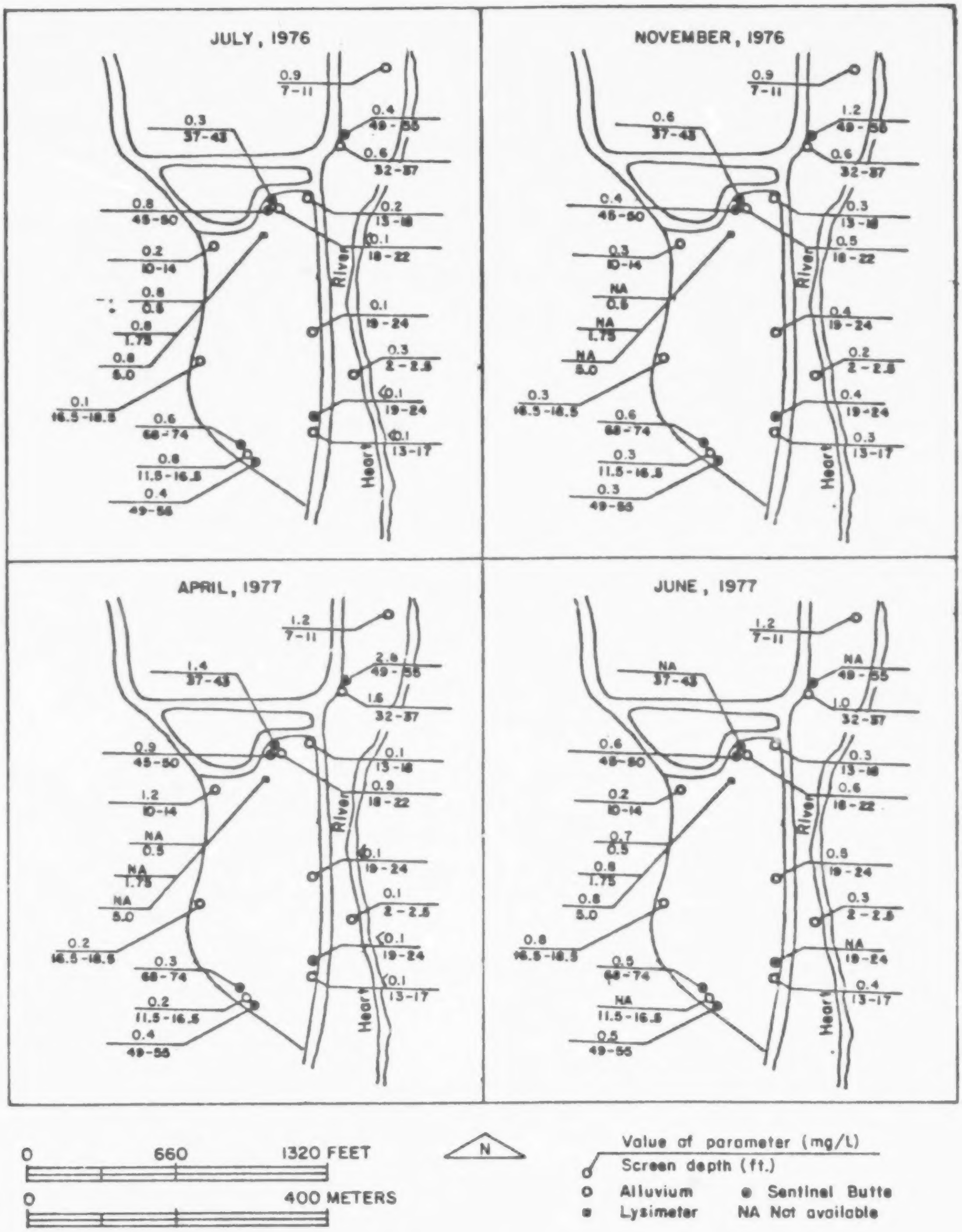

JULY, 1976
0.3
39-44
0.2
17-28
0.3
21-27
0.4
13-18
0.2
8-18
0.3
29.5-33.5
0.5
54-60
0.3
15-20
0.3
34-44
Heart
River
NOVEMBER. 1976
0.2
39-44
0.2
17-28
0.3
21-27
0.2
13-18
0.4
8-18
0.4
29.5-33.5
0.8
54-60
0.2
15-20
0.2
34-44
Heart
River
APRIL, 1977
0.1
39-44
NA
17-28
<0.1
21-27
NA
13-18
0.3
8-18
0.3
29.5-33.5
0.2
54-60
0.1
15-20
NA
34-44
Heart
River
JUNE, 1977
0.4
39-44
NA
17-28
0.3
21-27
NA
13-18
0.2
8-18
NA
29.5-33.5
NA
54-60
0.3
15-20
NA
34-44
Heart
River
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
o Alluvium
● Sentinel Butte
▫ Lysimeter
NA Not available

Figure 16. Control site groundwater constituents-ammonium nitrogen.



JULY, 1976
NOVEMBER, 1976
APRIL, 1977
JUNE, 1977
Heart River
0 660 1320 FEET
0 400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
■ Lysimeter
NA Not available

Figure 17. Test site groundwater constituents-ammonium nitrogen.

the test site yielded an average concentration of <0.43 mg/L ammonium nitrogen for 30 analyses as compared with an average concentration of <0.28 mg/L for 28 analyses at the control site.

The April, 1977, sampling produced generally the lowest concentrations for the wells not influenced by lagoon leakage and the highest concentrations for wells affected by leakage.

Concentrations at the western edge of the test site in the area not influenced by leakage were generally greater than those observed at the eastern edge. This indicated that ammonium nitrogen was decreasing along the direction of groundwater flow. The average of 15 analyses from the eastern edge was <0.23 mg/L. This compared favorably with the control site results. Therefore, since the discharge point for treated groundwater was the Heart River at the eastern edge of the test site, the Dickinson land treatment system appeared to satisfactorily reduce ammonium nitrogen to observed background levels. No correlations in concentrations were observed with depth or between the alluvium and Sentinel Butte aquifers.

Soluble organic nitrogen concentrations ranged from 0.2 to 1.9 mg/L at the control site (Figure 18) and from <0.1 to 3.8 mg/L at the test site (Figure 19). Again, the wells with groundwater influenced by lagoon leakage accounted for the concentrations in the higher range.

The wells unaffected by leakage in the test site area yielded an average concentration of <1.2 mg/L of soluble orgainic nitrogen for 30 analyses as compared to an average concentration of <0.56 mg/L for 28 analyses at the control site. Thus, small amounts of organic nitrogen from the effluent appeared to be passing through the soil column at the test site.

The range of concentration of soluble organic nitrogen in the lagoon effluent was <0.1 to 11.4 mg/L. It was likely that the high instantaneous rates of application associated with the border-strip irrigation method, as practiced at this location, did not provide sufficient time for the organic nitrogen to adsorb and biologically decompose on the soil absorption sites. No regular gradient with depth or with direction of groundwater flow could be detected in the alluvium or Sentinel Butte aquifers.

The June, 1977, sampling produced concentrations of 15.7 and 6.4 mg/L at the 0.15 m (0.5 ft) and 1.5 m (5 ft) depth lysimeters, respectively. The lysimeter results can only be informative when viewed against other comparable lysimeter results.

Nitrate nitrogen concentrations in the wells ranged from <0.1 to 1.9 mg/L at the control site (Figure 20) and from <0.1 to 20.0 mg/L at the test site (Figure 21). At the control site, concentrations averaged <0.41 mg/L for 28 analyses, while at the test site concentrations averaged 1.78 mg/L for 61 analyses. Results showed concentrations at both sites to be generally higher in July and November, 1976, than in April and June, 1977. This corresponded to somewhat greater soil temperatures in late summer and fall and to increased nitrification activity. Nitrate concentrations in the alluvium water at the control site were greater than those of the Sentinel Butte.

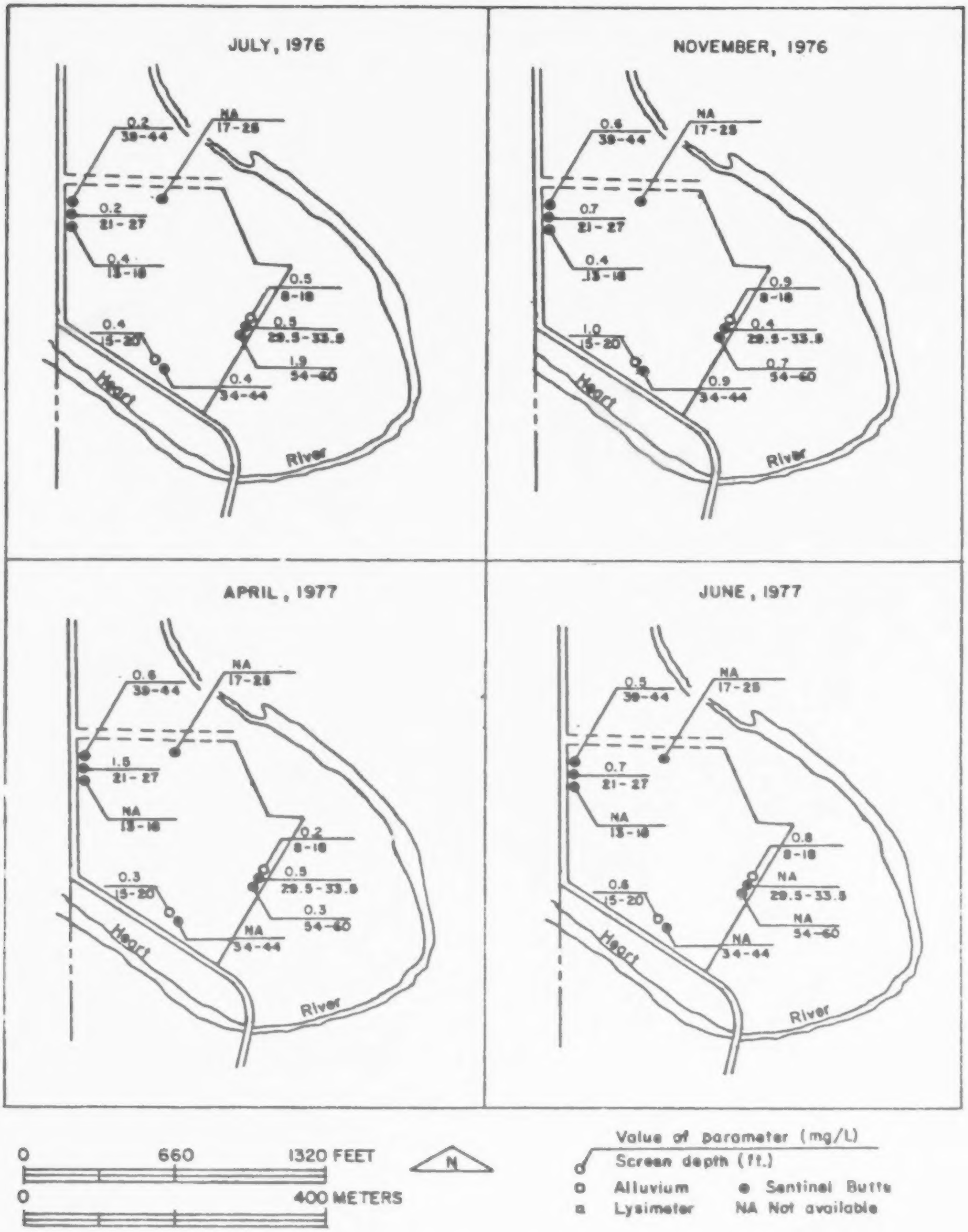

JULY, 1976
0.2 39-44
NA 17-28
0.2 21-27
0.4 13-18
0.5 8-18
0.5 29.5-33.8
1.9 54-60
0.4 34-44
0.4 15-20
Heart
River
NOVEMBER, 1976
0.6 39-44
NA 17-28
0.7 21-27
0.4 13-18
0.9 8-18
0.4 29.5-33.8
0.7 54-60
0.9 34-44
1.0 15-20
Heart
River
APRIL, 1977
0.6 39-44
NA 17-28
1.8 21-27
NA 13-18
0.2 8-18
0.5 29.5-33.8
0.3 54-60
NA 34-44
0.3 15-20
Heart
River
JUNE, 1977
0.5 39-44
NA 17-28
0.7 21-27
NA 13-18
0.8 8-18
NA 29.5-33.8
NA 54-60
NA 34-44
0.6 15-20
Heart
River
0 660 1320 FEET
0 400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
□ Lysimeter
NA Not available

Figure 18. Control site groundwater constituents - soluble organic nitrogen.

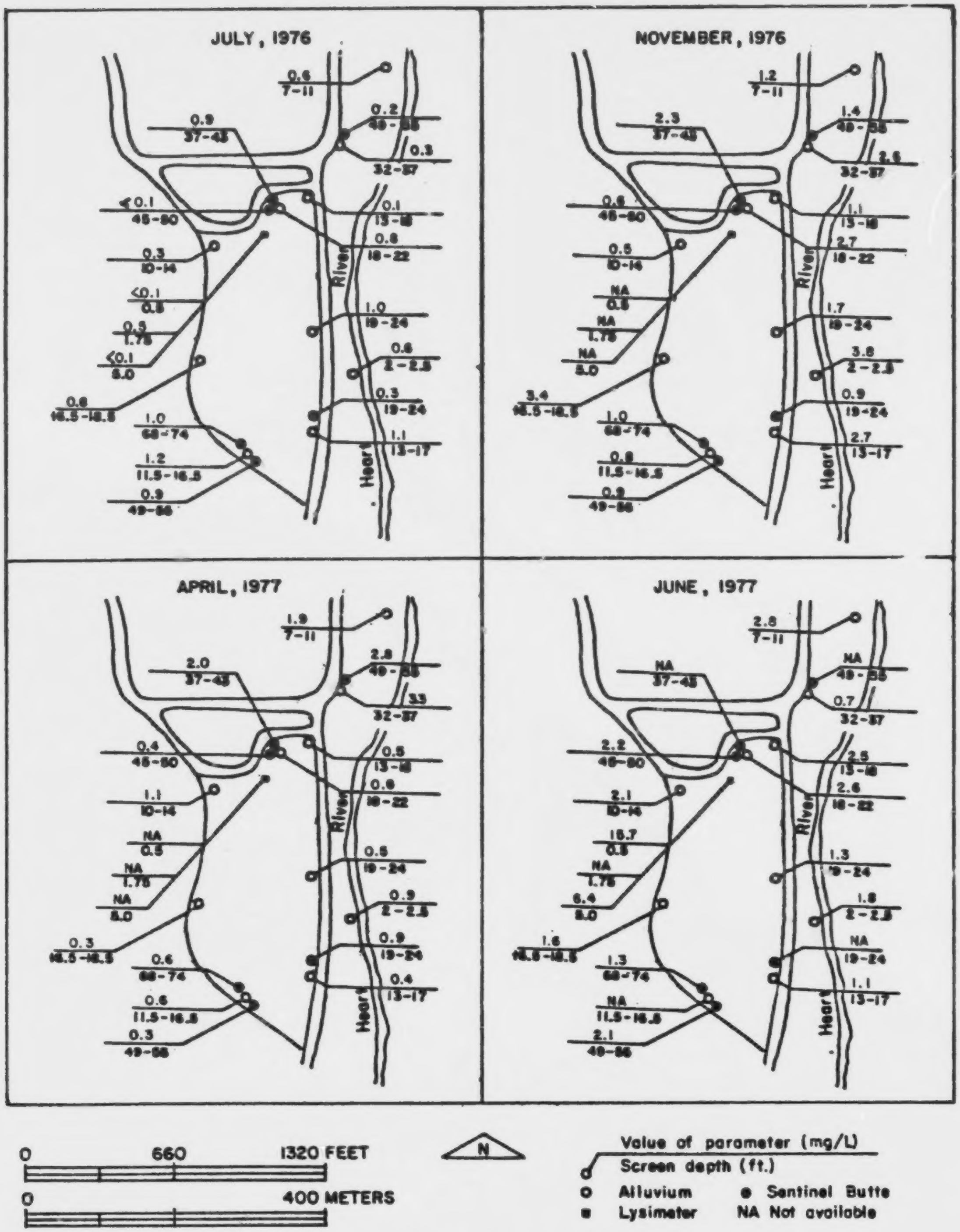

JULY, 1976
0.6
7-11
0.2
49-55
0.3
32-37
0.9
37-43
<0.1
45-50
0.1
13-18
0.8
18-22
0.3
10-14
<0.1
0.5
0.5
1.75
<0.1
5.0
1.0
19-24
0.6
2-2.5
0.3
19-24
0.6
16.5-18.5
1.0
68-74
1.1
13-17
1.2
11.5-16.5
0.9
49-56
River
Heart
NOVEMBER, 1976
1.2
7-11
1.4
49-55
2.5
32-37
2.3
37-43
0.6
45-50
1.1
13-18
2.7
18-22
0.5
10-14
NA
0.5
NA
1.75
NA
5.0
1.7
19-24
3.8
2-2.5
3.4
16.5-18.5
0.9
19-24
1.0
68-74
2.7
13-17
0.8
11.5-16.5
0.9
49-56
River
Heart
APRIL, 1977
1.9
7-11
2.8
49-55
33
32-37
2.0
37-43
0.4
45-50
0.5
13-18
0.8
18-22
1.1
10-14
NA
0.5
NA
1.75
NA
5.0
0.5
19-24
0.9
2-2.5
0.3
16.5-18.5
0.9
19-24
0.6
68-74
0.4
13-17
0.6
11.5-16.5
0.3
49-56
River
Heart
JUNE, 1977
2.8
7-11
NA
49-55
0.7
32-37
NA
37-43
2.2
45-50
2.5
13-18
2.6
18-22
2.1
10-14
16.7
0.5
NA
1.75
6.4
5.0
1.3
19-24
1.8
2-2.5
1.6
16.5-18.5
NA
19-24
1.3
68-74
1.1
13-17
NA
11.5-16.5
2.1
49-56
River
Heart
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
Alluvium
Sentinel Butte
Lysimeter
NA Not available

Figure 19. Test site groundwater constituents—soluble organic nitrogen.

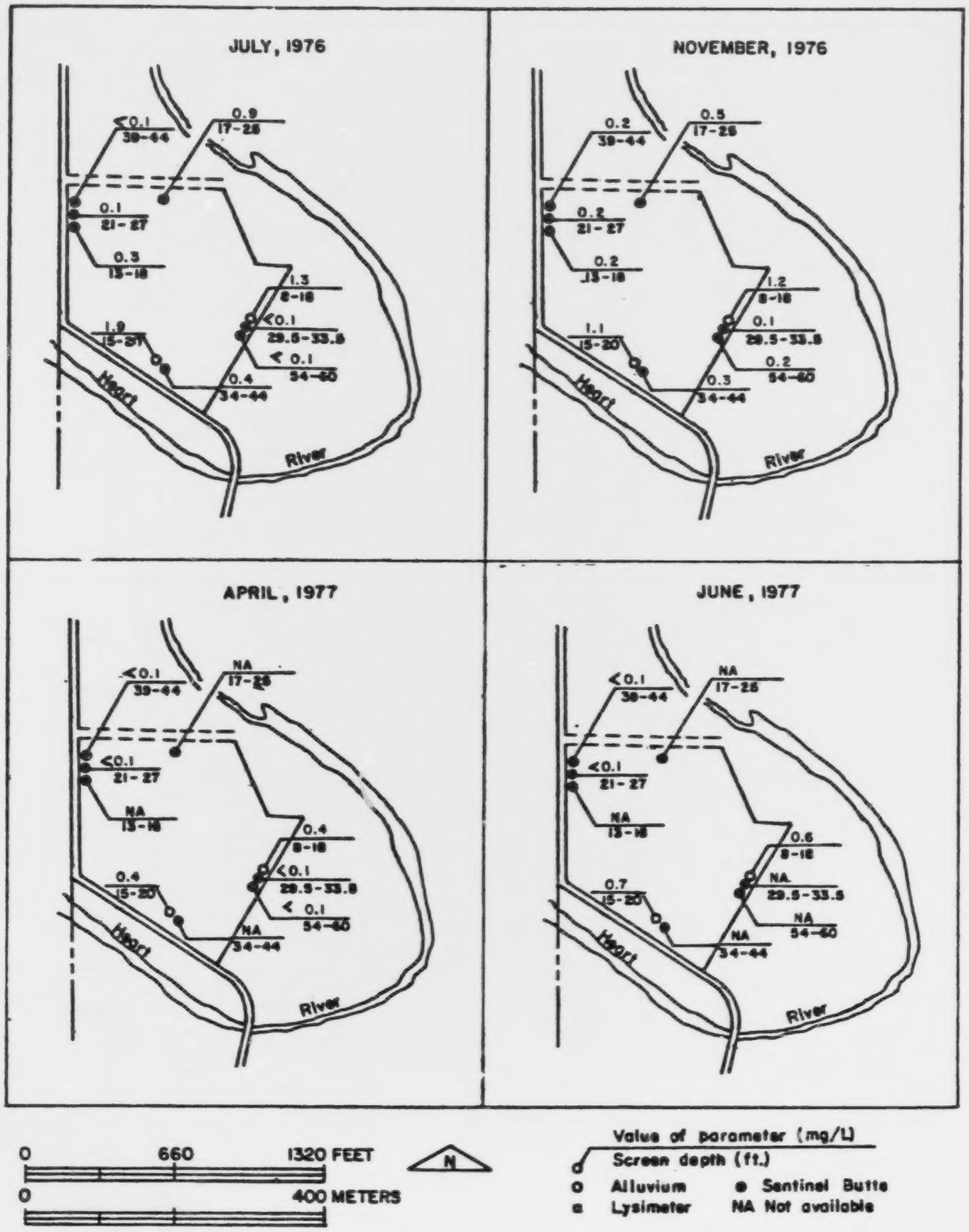

JULY, 1976
<0.1
39-44
0.9
17-26
0.1
21-27
0.3
13-18
1.3
8-18
<0.1
29.5-33.5
< 0.1
54-60
1.9
15-20
0.4
34-44
Heart
River
NOVEMBER, 1976
0.2
39-44
0.5
17-26
0.2
21-27
0.2
13-18
1.2
8-18
0.1
29.5-33.5
0.2
54-60
1.1
15-20
0.3
34-44
Heart
River
APRIL, 1977
<0.1
39-44
NA
17-26
<0.1
21-27
NA
13-18
0.4
8-18
<0.1
29.5-33.5
< 0.1
54-60
0.4
15-20
NA
34-44
Heart
River
JUNE, 1977
<0.1
39-44
NA
17-26
<0.1
21-27
NA
13-18
0.6
8-18
NA
29.5-33.5
NA
54-60
0.7
15-20
NA
34-44
Heart
River
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
▫ Lysimeter
NA Not available

Figure 20. Control site groundwater constituents—nitrate nitrogen.

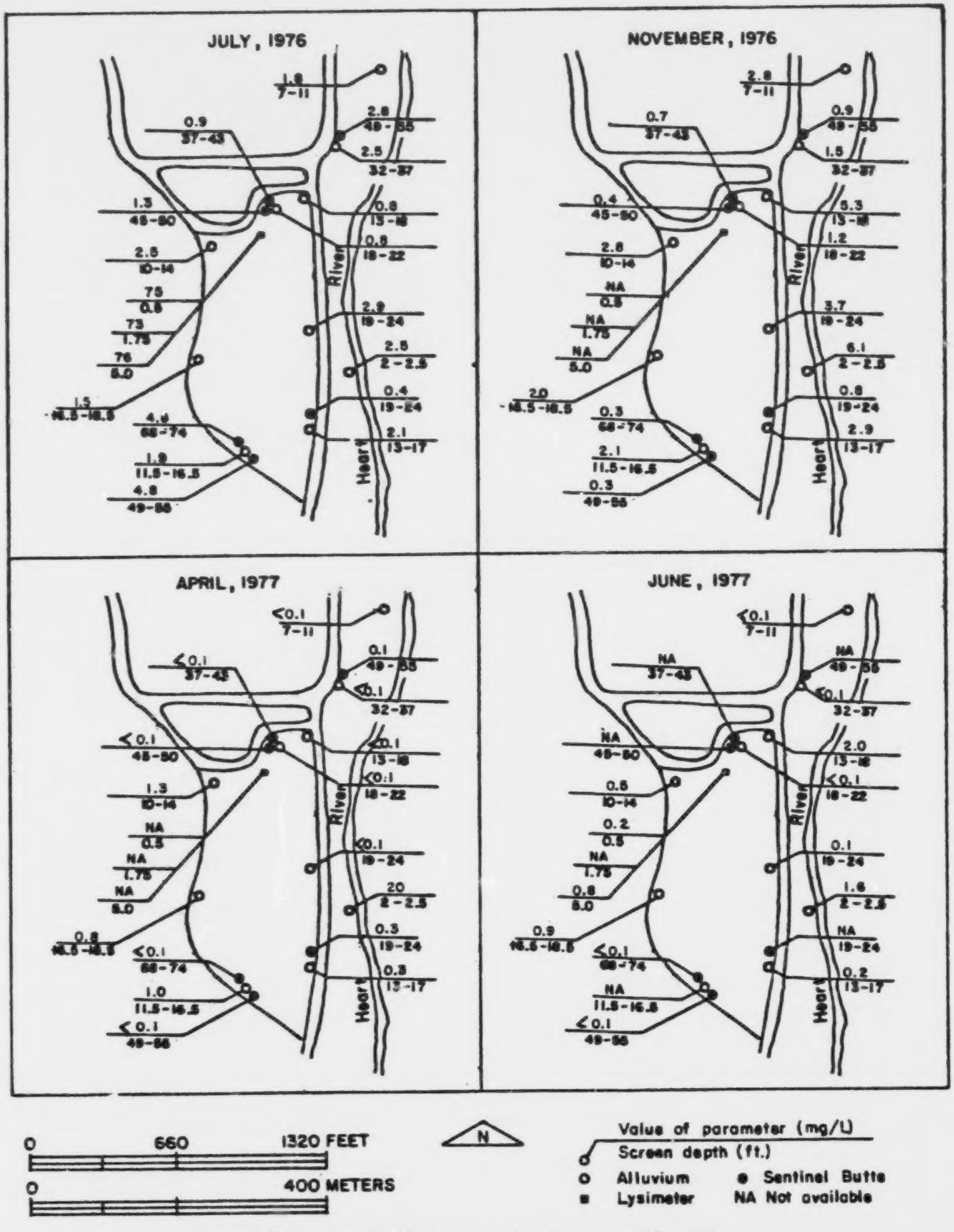

JULY, 1976
1.8 / 7-11
2.8 / 49-55
0.9 / 37-43
2.5 / 32-37
1.3 / 45-50
0.8 / 13-18
0.8 / 18-22
2.5 / 10-14
75 / 0.5
73 / 1.75
76 / 5.0
2.9 / 19-24
2.5 / 2-2.5
0.4 / 19-24
1.5 / 16.5-18.5
4.9 / 68-74
2.1 / 13-17
1.9 / 11.5-16.5
4.8 / 49-55
River
Heart
NOVEMBER, 1976
2.8 / 7-11
0.9 / 49-55
0.7 / 37-43
1.5 / 32-37
0.4 / 45-50
5.3 / 13-18
1.2 / 18-22
2.8 / 10-14
NA / 0.5
NA / 1.75
NA / 5.0
3.7 / 19-24
6.1 / 2-2.5
2.0 / 16.5-18.5
0.8 / 19-24
0.3 / 68-74
2.9 / 13-17
2.1 / 11.5-16.5
0.3 / 49-55
River
Heart
APRIL, 1977
<0.1 / 7-11
0.1 / 49-55
<0.1 / 37-43
<0.1 / 32-37
<0.1 / 45-50
<0.1 / 13-18
<0.1 / 18-22
1.3 / 10-14
NA / 0.5
NA / 1.75
NA / 5.0
<0.1 / 19-24
20 / 2-2.5
0.8 / 16.5-18.5
0.3 / 19-24
<0.1 / 68-74
0.3 / 13-17
1.0 / 11.5-16.5
<0.1 / 49-55
River
Heart
JUNE, 1977
<0.1 / 7-11
NA / 49-55
NA / 37-43
<0.1 / 32-37
NA / 45-50
2.0 / 13-18
<0.1 / 18-22
0.5 / 10-14
0.2 / 0.5
NA / 1.75
0.8 / 5.0
0.1 / 19-24
1.6 / 2-2.5
0.9 / 16.5-18.5
NA / 19-24
<0.1 / 68-74
0.2 / 13-17
NA / 11.5-16.5
<0.1 / 49-55
River
Heart
0 660 1320 FEET
0 400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
o Alluvium
● Sentinel Butte
▪ Lysimeter
NA Not available

Figure 21. Test site groundwater constituents - nitrate nitrogen.

However, no other gradient with depth or with direction of groundwater flow in the alluvium was observed.

Lysimeter samples 224101, 224201, and 224301 taken in July, 1976, had nitrate nitrogen concentrations of 75, 73, and 76 mg/L, respectively. These concentrations probably reflect the intense nitrifying activity in the shallow root zones of the pasture prior to complete crop uptake and denitrification processes and a concentrating effect due to recovery of samples under vacuum from the unsaturated zone. All other concentrations were well within the bounds of expectation and did not approach the maximum acceptable drinking water standard of 10 mg/L.

Chemical Oxygen Demand (COD)--

COD concentrations ranged from 14 to 27 mg/L and from 4 to 32 mg/L in the alluvium and Sentinel Butte control site aquifers, respectively (Figure 22). However, a concentration of 36 mg/L was observed at well 21150 outside the control site.

In an area of the test site alluvium aquifer not affected by lagoon leakage, COD concentrations ranged from 52 to 109 mg/L, while the Sentinel Butte aquifer concentrations ranged from 11 to 83 mg/L (Figure 23).

In the northern test site area affected by lagoon leakage, concentrations ranged from 28 to 82 mg/L in the alluvium aquifer and from 32 to 78 mg/L in the Sentinel Butte aquifer. Although lagoon leakage might be expected to diminish COD treatment capability and the minimum COD concentration was lower in the Sentinel Butte aquifer, the treatment performance was not markedly different at the test site, regardless of location or aquifer.

Further examination of test site samples indicated a regularly occurring gradient in COD concentrations along the direction of groundwater flow. Well pairs 22070 and 22050, 22190 and 22200, 22100 and 22110, and 22020 and 22090 show an average concentration of 79 mg/L at the west side of the test site and 56 mg/L at the east side. This reduction of 23 mg/L was generally along the direction of groundwater flow. Almost all the high individual COD concentrations were observed along the west side of the test site. The existence of this gradient suggests several possibilities: (1) there was higher effluent application along the west side of the test site; (2) the groundwater entering the site had higher COD concentration than either the test or control site groundwater; or (3) the saturated alluvium was capable of further reducing COD.

The COD concentrations of the alluvium wells at the eastern boundary of the test site ranged from 28 to 113 mg/L and averaged 56 mg/L, which was consistent with the COD concentrations measured in the Dickinson potable and irrigation water supply from Patterson Lake of 52 to 60 mg/L, respectively. This suggested that the organics introduced from Dickinson domestic sewage could be removed before the groundwater flowed from the test site to the Heart River. The more refractory COD constituents present in the original potable supply might be more readily removed through application on the control site than on the test site, as was shown by the quality of the groundwater within the control site. A possible explanation is the competition of

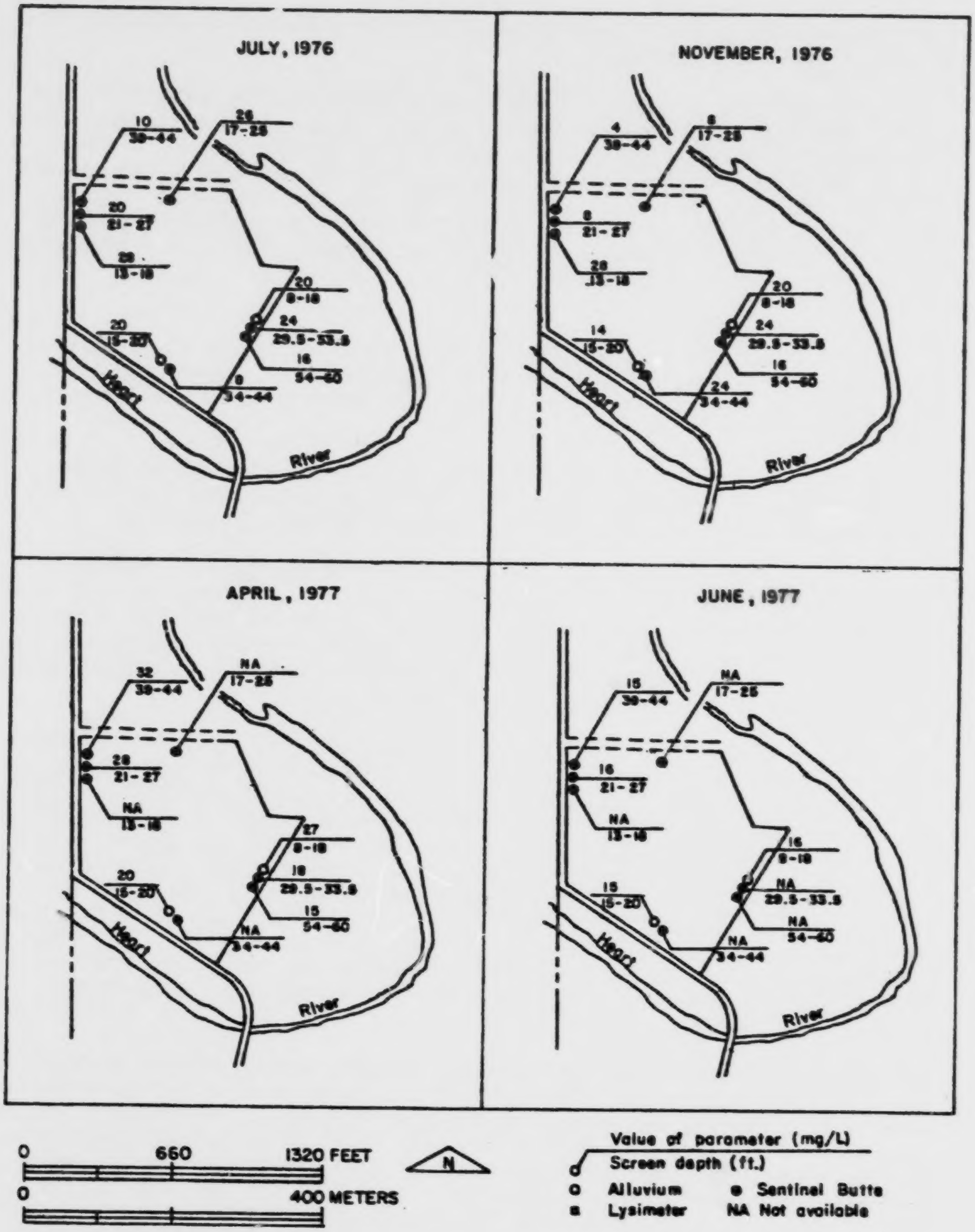

JULY, 1976
10
39-44
26
17-25
20
21-27
28
13-18
20
9-18
24
29.5-33.5
16
54-60
20
15-20
8
34-44
Heart
River
NOVEMBER, 1976
4
39-44
8
17-25
8
21-27
28
13-18
20
9-18
24
29.5-33.5
16
54-60
14
15-20
24
34-44
Heart
River
APRIL, 1977
32
39-44
NA
17-25
28
21-27
NA
13-18
27
9-18
18
29.5-33.5
15
54-60
20
15-20
NA
34-44
Heart
River
JUNE, 1977
15
39-44
NA
17-25
16
21-27
NA
13-18
16
9-18
NA
29.5-33.5
NA
54-60
15
15-20
NA
34-44
Heart
River
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
■ Lysimeter
NA Not available

Figure 22. Control site groundwater constituents - chemical oxygen demand.

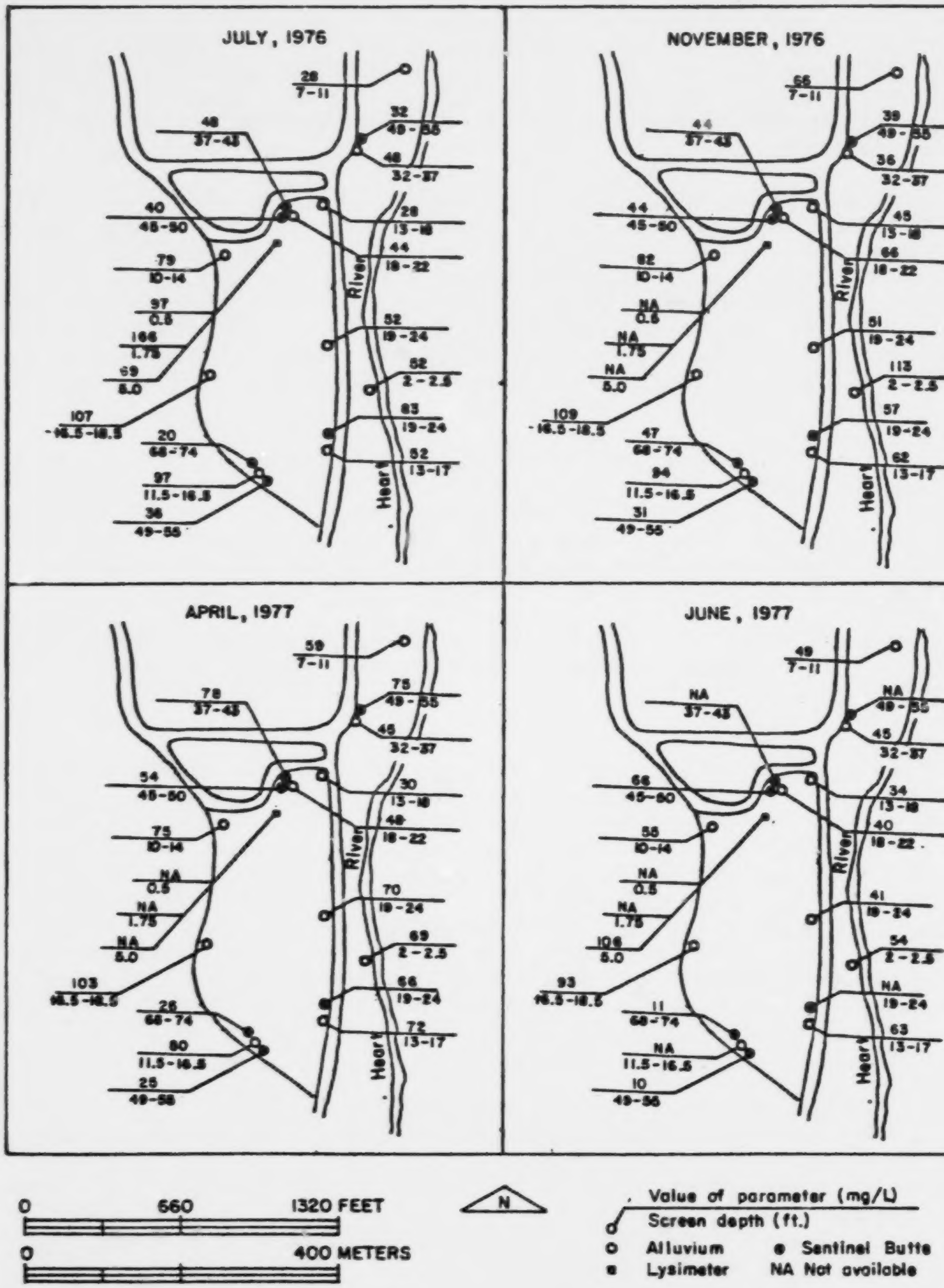

JULY, 1976
28
7-11
48
37-43
32
49-55
48
32-37
40
45-50
28
13-18
44
18-22
79
10-14
97
0.5
166
1.75
69
5.0
52
19-24
52
2-2.5
107
16.5-18.5
83
19-24
20
68-74
52
13-17
97
11.5-16.5
36
49-55
River
Heart
NOVEMBER, 1976
66
7-11
44
37-43
39
49-55
36
32-37
44
45-50
45
13-18
66
18-22
82
10-14
NA
0.5
NA
1.75
NA
5.0
51
19-24
113
2-2.5
109
16.5-18.5
57
19-24
47
68-74
62
13-17
94
11.5-16.5
31
49-55
River
Heart
APRIL, 1977
59
7-11
78
37-43
75
49-55
45
32-37
54
45-50
30
13-18
48
18-22
75
10-14
NA
0.5
NA
1.75
NA
5.0
70
19-24
69
2-2.5
103
16.5-18.5
66
19-24
26
68-74
72
13-17
80
11.5-16.5
25
49-55
River
Heart
JUNE, 1977
49
7-11
NA
37-43
NA
49-55
45
32-37
66
45-50
34
13-18
40
18-22
58
10-14
NA
0.5
NA
1.75
106
5.0
41
19-24
54
2-2.5
93
16.5-18.5
NA
19-24
11
68-74
63
13-17
NA
11.5-16.5
10
49-55
River
Heart
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
■ Lysimeter
NA Not available

Figure 23. Test site groundwater constituents-chemical oxygen demand.

organic compounds for the adsorptive sites within the soil. Adsorption sites in the test site area soils were more readily occupied by the greater number of treatable organic compounds, thus allowing the more refractory compounds to percolate through the soil. In the control area the competition for sites was greatly reduced, therefore allowing for more adsorption of refractory organic compounds.

In the alluvium the average COD concentration at the control site was 19 mg/L, while the average test site concentration prior to discharge into the Heart River was 56 mg/L (Table 8). This difference could be explained by a higher concentration of refractory organics introduced through the potable water supply, which required more contact with irrigation soils for treatment to the residual level observed at the control site. Another possibility was that higher COD concentrations were entering the test site alluvium from the west and dilution from irrigated wastewater was occurring across the site.

Potassium--

In the water sampled, concentrations of potassium ranged from 1.8 to 8.7 mg/L at the control site (Figure 24) and from 4 to 24 mg/L at the test site (Figure 25). Lysimeter sample concentrations ranged from 11 to 34 mg/L at the test site. The average concentration observed at the control site was 5.6 mg/L based on 30 analyses and at the test site was 11.6 mg/L based on analyses. The effluent potassium concentration averaged 24 mg/L.

There was no correlation of potassium concentration with direction of groundwater flow, depth, alluvium or Sentinel Butte aquifer, or round of sampling.

Chloride--

Both the range and the average chloride concentrations in the shallow to mid-depth test site wells exceeded those in the control site wells. Typical concentrations found in control and test site wells were 25 mg/L and 100 mg/L, respectively (Figures 26 and 27). Chloride concentrations averaged 30 mg/L in the deeper Sentinel Butte test site wells, such as 22130, 22060, and 22080, as opposed to an average 103 mg/L for alluvium wells, thus indicating a major separation of the deeper portions of the aquifer from the shallower groundwater flows affected by wastewater irrigation. The effluent chloride concentration was 83 mg/L. Since chloride is a refractory ion that passes through a column of soil relatively unaffected, the presence of chloride in the groundwater serves as a good indicator that some form of wastewater irrigation has been applied to the land.

Sodium, Calcium, Magnesium, Sulfate, and Dissolved Solids--

Typical test site concentrations for sodium, calcium, magnesium, sulfate, and dissolved solids were 600, 600, 330, 3,200, and 5,800 mg/L, respectively, (Figure 28 and Appendix B) for an area unaffected by lagoon leakage. Control site concentrations for the same parameters were 300, 100, 30, 600, and 1,200 mg/L (Figure 29). The wide differences between the test and control site concentrations can be attributed to the more mineralized soils in the test site as opposed to the control site. The complete soil data are presented in Appendix B.

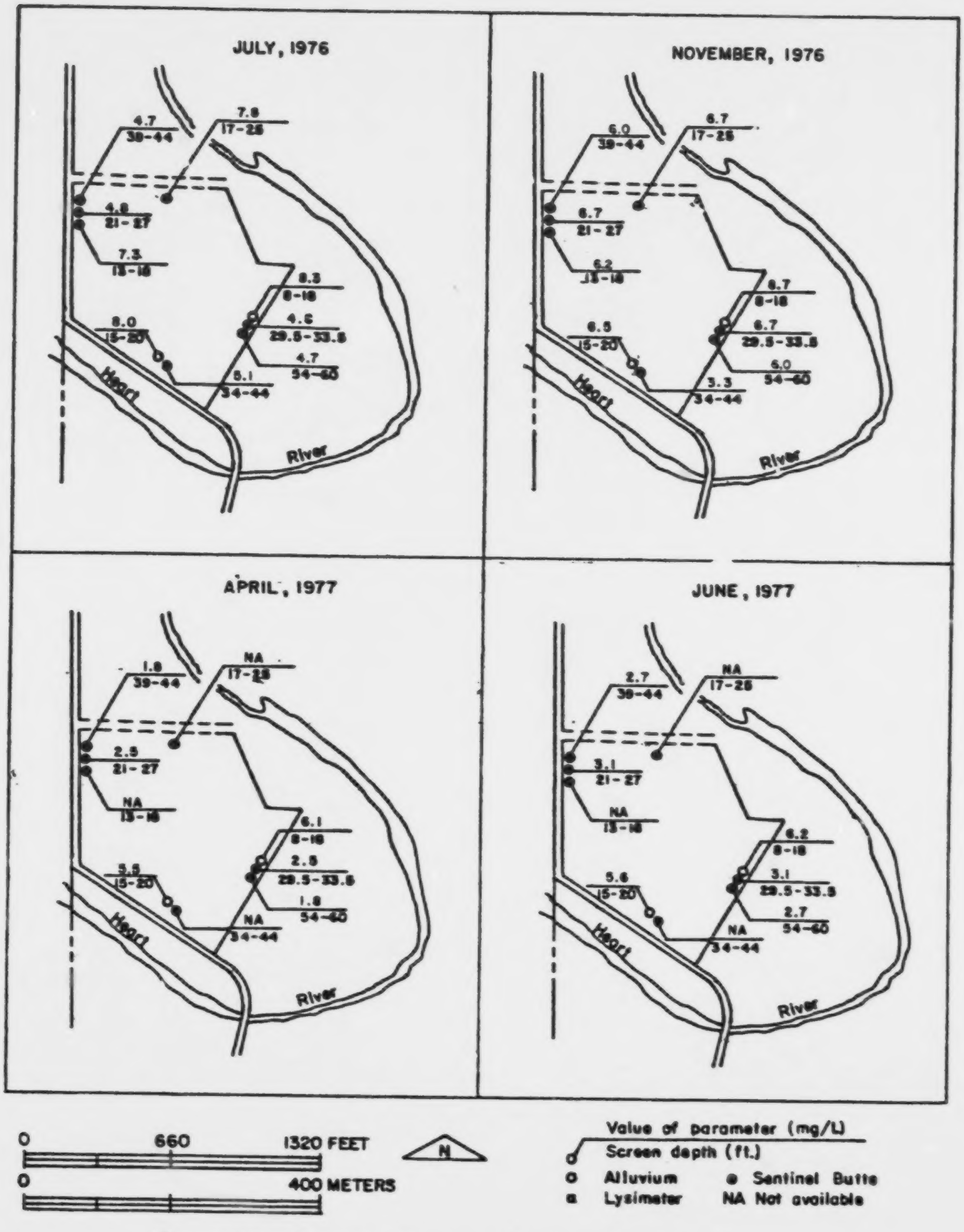

JULY, 1976
4.7
39-44
7.8
17-28
4.8
21-27
7.3
13-18
8.3
8-18
8.0
15-20
4.6
29.5-33.5
4.7
54-60
5.1
34-44
Heart
River
NOVEMBER, 1976
6.0
39-44
6.7
17-28
6.7
21-27
6.2
13-18
6.7
8-18
6.5
15-20
6.7
29.5-33.5
6.0
54-60
3.3
34-44
Heart
River
APRIL, 1977
1.8
39-44
NA
17-28
2.5
21-27
NA
13-18
6.1
8-18
5.5
15-20
2.5
29.5-33.5
1.8
54-60
NA
34-44
Heart
River
JUNE, 1977
2.7
39-44
NA
17-28
3.1
21-27
NA
13-18
6.2
8-18
5.6
15-20
3.1
29.5-33.5
2.7
54-60
NA
34-44
Heart
River
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
o Alluvium
● Sentinel Butte
▫ Lysimeter
NA Not available

Figure 24. Control site groundwater constituents-potassium.

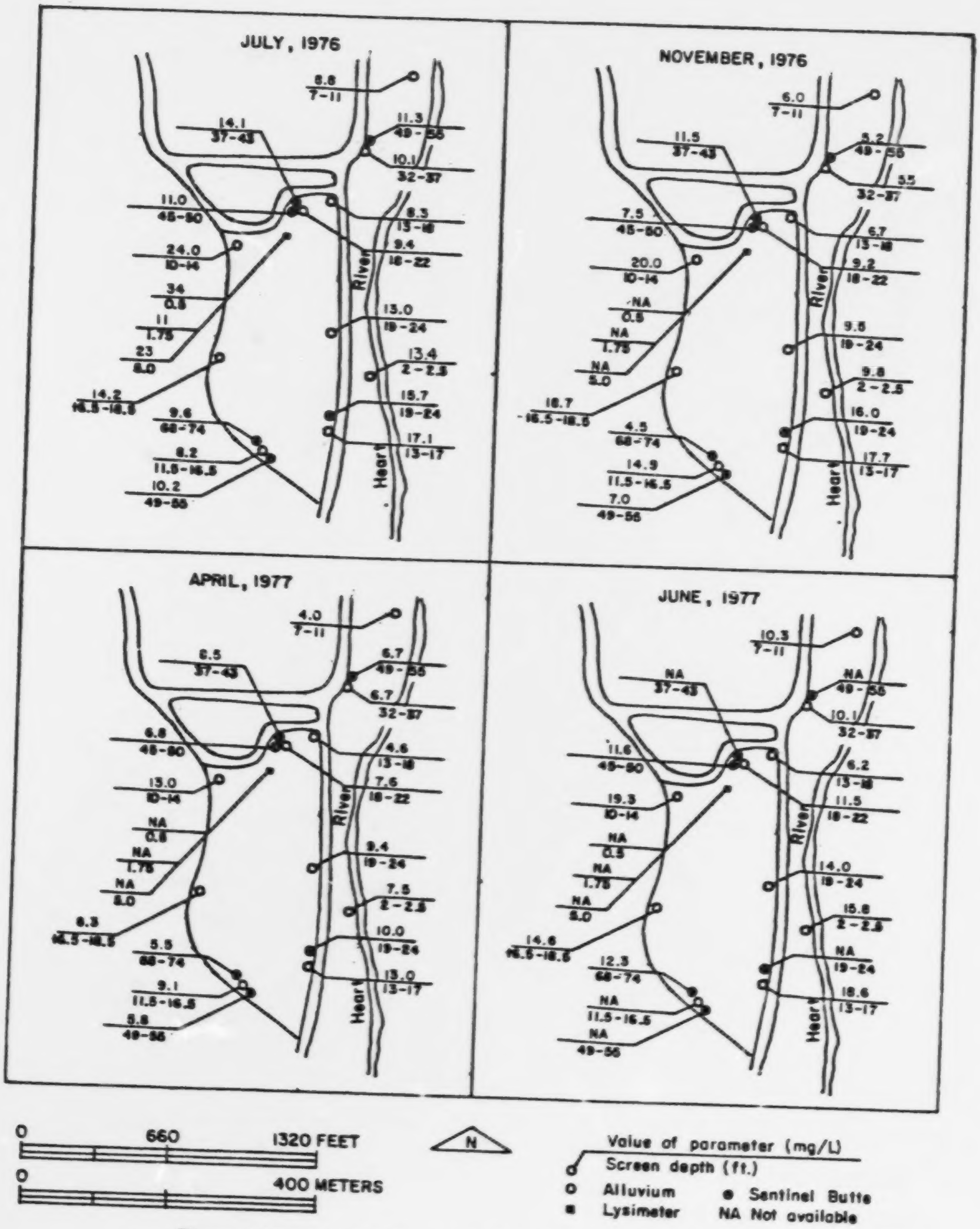

JULY, 1976
8.8 7-11
14.1 37-43
11.3 49-55
10.1 32-37
11.0 45-50
8.3 13-18
9.4 18-22
24.0 10-14
34 0.5
11 1.75
23 5.0
13.0 19-24
13.4 2-2.5
14.2 16.5-18.5
15.7 19-24
9.6 68-74
17.1 13-17
8.2 11.5-16.5
10.2 49-55
Heart River
NOVEMBER, 1976
6.0 7-11
11.5 37-43
5.2 49-55
5.5 32-37
7.5 45-50
6.7 13-18
9.2 18-22
20.0 10-14
NA 0.5
NA 1.75
NA 5.0
9.6 19-24
9.8 2-2.5
18.7 16.5-18.5
16.0 19-24
4.5 68-74
17.7 13-17
14.9 11.5-16.5
7.0 49-55
Heart River
APRIL, 1977
4.0 7-11
6.5 37-43
6.7 49-55
6.7 32-37
6.8 45-50
4.6 13-18
7.6 18-22
13.0 10-14
NA 0.5
NA 1.75
NA 5.0
9.4 19-24
7.5 2-2.5
8.3 16.5-18.5
10.0 19-24
5.5 68-74
13.0 13-17
9.1 11.5-16.5
5.8 49-55
Heart River
JUNE, 1977
10.3 7-11
NA 37-43
NA 49-55
10.1 32-37
11.6 45-50
6.2 13-18
11.5 18-22
19.3 10-14
NA 0.5
NA 1.75
NA 5.0
14.0 19-24
15.8 2-2.5
14.6 16.5-18.5
NA 19-24
12.3 68-74
18.6 13-17
NA 11.5-16.5
NA 49-55
Heart River
0 660 1320 FEET
0 400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
■ Lysimeter
NA Not available

Figure 25. Test site groundwater constituents-potassium.

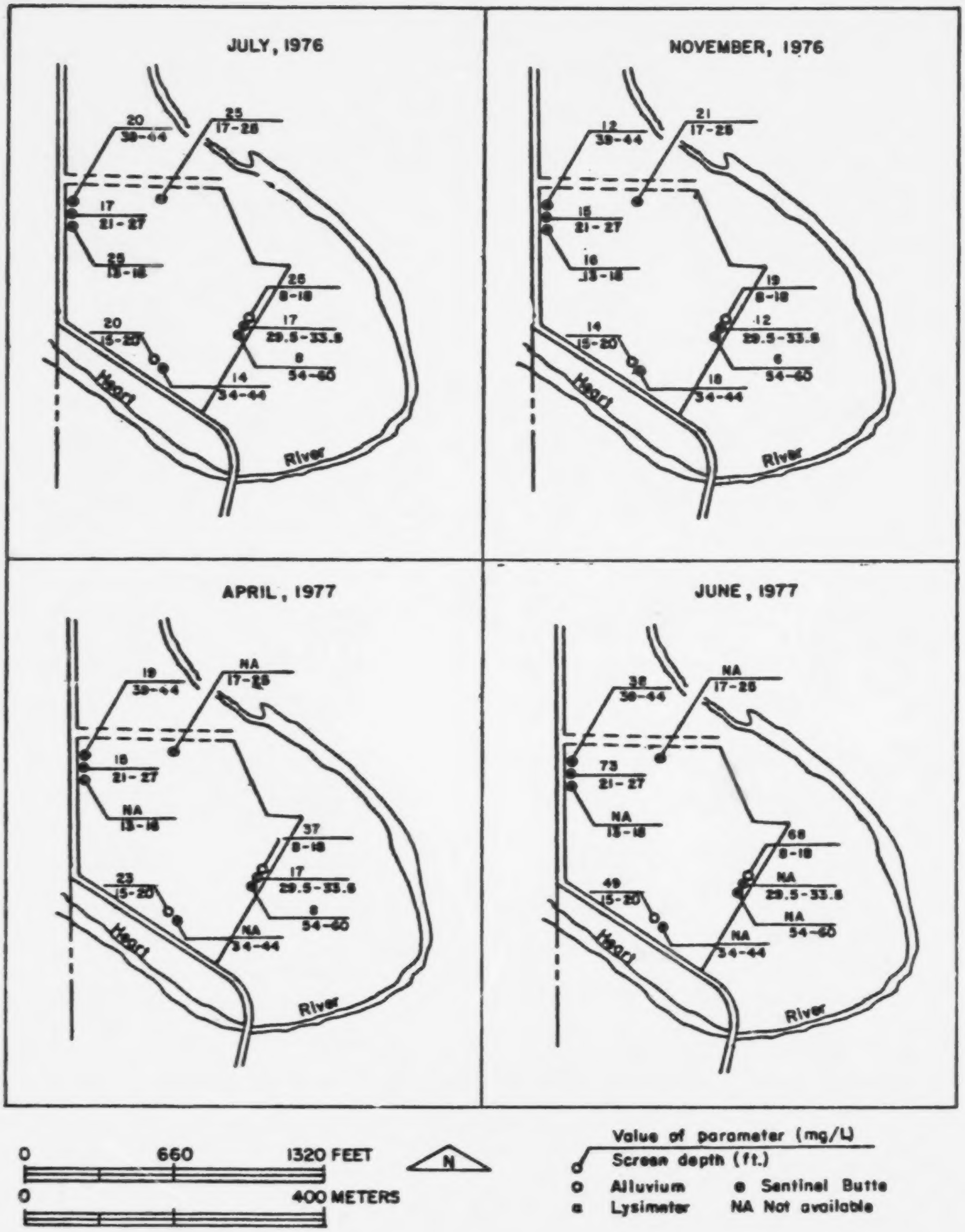

JULY, 1976
20
38-44
25
17-28
17
21-27
28
13-18
26
8-18
17
29.5-33.8
8
54-60
20
15-20
14
34-44
Heart
River
NOVEMBER, 1976
12
38-44
21
17-28
15
21-27
16
13-18
19
8-18
12
29.5-33.8
6
54-60
14
15-20
18
34-44
Heart
River
APRIL, 1977
19
38-44
NA
17-28
18
21-27
NA
13-18
37
8-18
17
29.5-33.8
8
54-60
23
15-20
NA
34-44
Heart
River
JUNE, 1977
38
38-44
NA
17-28
73
21-27
NA
13-18
68
8-18
NA
29.5-33.8
NA
54-60
49
15-20
NA
34-44
Heart
River
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
▪ Lysimeter
NA Not available

Figure 26. Control site groundwater constituents–chloride.

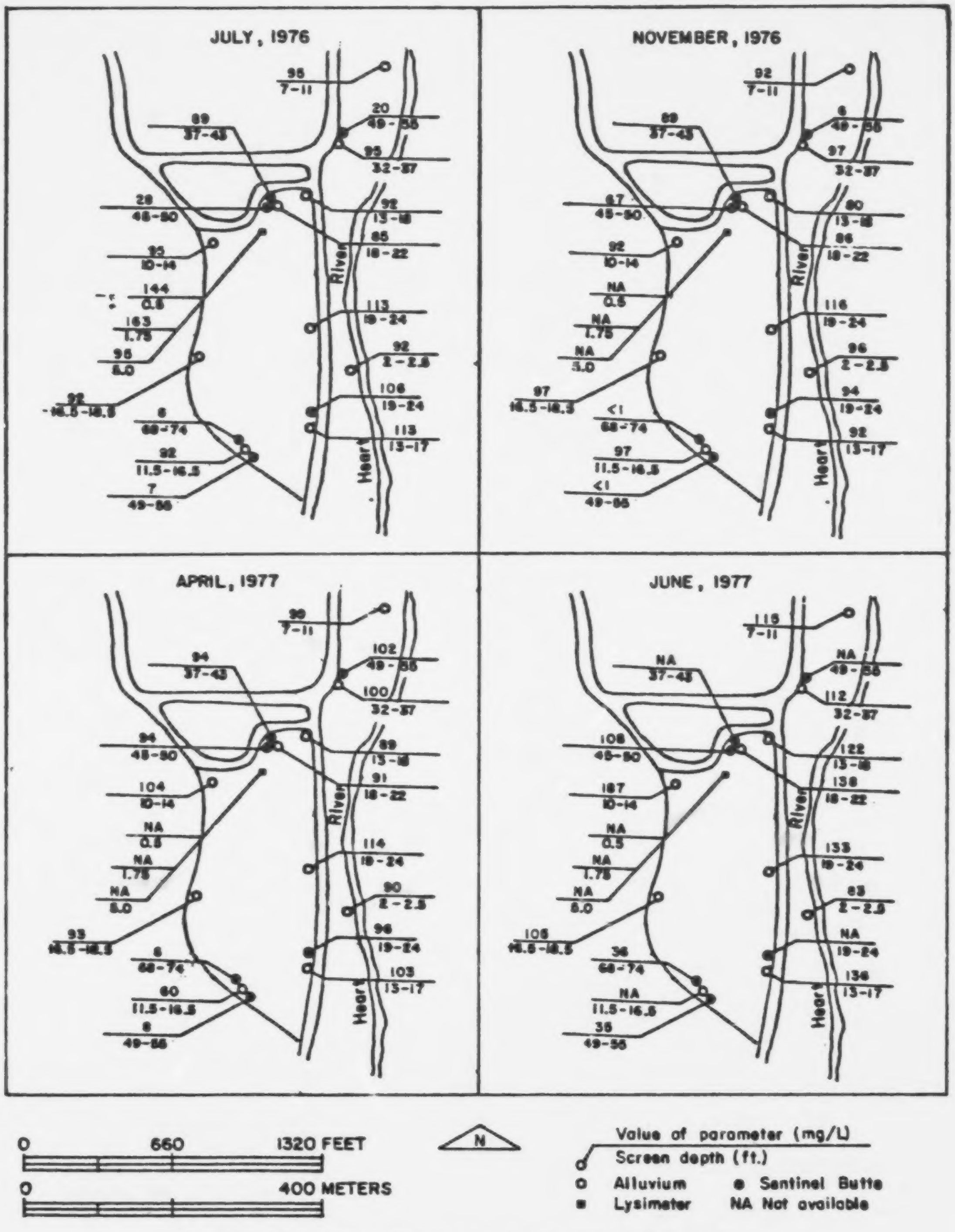

JULY, 1976
95
7-11
20
49-56
89
37-43
95
32-37
28
45-50
92
13-18
85
18-22
95
10-14
144
0.5
163
1.75
95
5.0
113
19-24
92
2-2.5
106
19-24
92
16.5-18.5
6
68-74
113
13-17
92
11.5-16.5
7
49-56
River
Heart
NOVEMBER, 1976
92
7-11
6
49-56
89
37-43
97
32-37
67
45-50
90
13-18
86
18-22
92
10-14
NA
0.5
NA
1.75
NA
5.0
116
19-24
96
2-2.5
97
16.5-18.5
94
19-24
<1
68-74
92
13-17
97
11.5-16.5
<1
49-56
River
Heart
APRIL, 1977
90
7-11
102
49-56
94
37-43
100
32-37
94
45-50
89
13-18
91
18-22
104
10-14
NA
0.5
NA
1.75
NA
5.0
114
19-24
90
2-2.5
93
16.5-18.5
96
19-24
6
68-74
103
13-17
60
11.5-16.5
8
49-56
River
Heart
JUNE, 1977
115
7-11
NA
49-56
NA
37-43
112
32-37
108
45-50
122
13-18
138
18-22
187
10-14
NA
0.5
NA
1.75
NA
5.0
133
19-24
83
2-2.5
106
16.5-18.5
NA
19-24
36
68-74
136
13-17
NA
11.5-16.5
35
49-56
River
Heart
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
■ Lysimeter
NA Not available

Figure 27. Test site groundwater constituents-chloride.

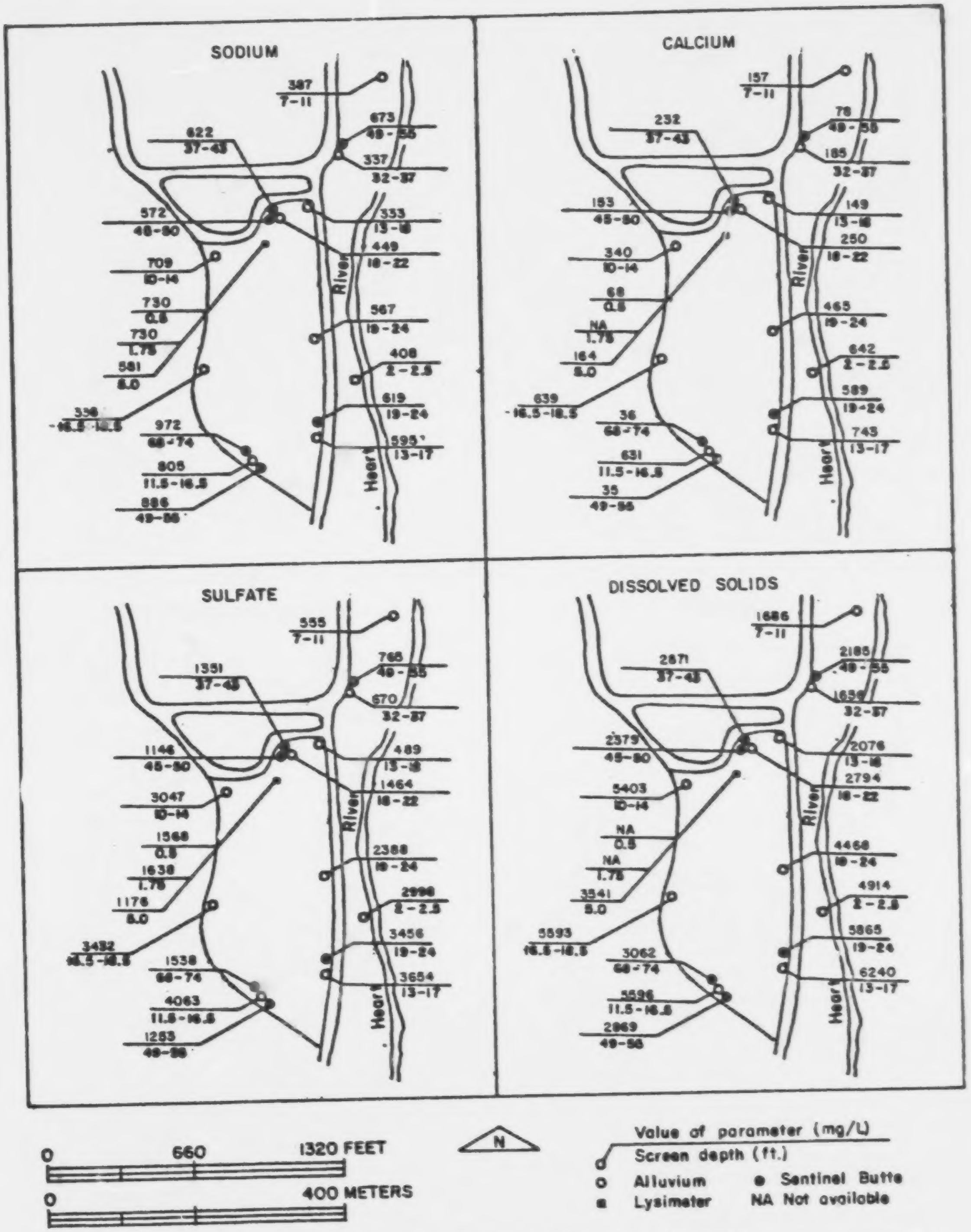

SODIUM
387
7-11
673
49-55
337
32-37
622
37-43
572
45-50
333
13-18
449
18-22
709
10-14
730
0.5
730
1.75
581
5.0
567
19-24
408
2-2.5
336
-16.5-18.5
972
68-74
619
19-24
595
13-17
805
11.5-16.5
886
49-56
River
Heart
CALCIUM
157
7-11
78
49-55
185
32-37
232
37-43
153
45-50
149
13-18
250
18-22
340
10-14
68
0.5
NA
1.75
164
5.0
465
19-24
642
2-2.5
639
-16.5-18.5
36
68-74
589
19-24
743
13-17
631
11.5-16.5
35
49-56
River
Heart
SULFATE
555
7-11
765
49-55
670
32-37
1351
37-43
1146
45-50
489
13-18
1464
18-22
3047
10-14
1568
0.5
1638
1.75
1176
5.0
2388
19-24
2996
2-2.5
3432
16.5-18.5
3456
19-24
1538
68-74
3654
13-17
4063
11.5-16.5
1253
49-56
River
Heart
DISSOLVED SOLIDS
1686
7-11
2185
49-55
1659
32-37
2871
37-43
2379
45-50
2076
13-18
2794
18-22
5403
10-14
NA
0.5
NA
1.75
3541
5.0
4468
19-24
4914
2-2.5
5593
16.5-18.5
5865
19-24
3062
68-74
6240
13-17
5596
11.5-16.5
2869
49-56
River
Heart
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
▪ Lysimeter
NA Not available

Figure 28. Test site groundwater constituents-selected parameters.

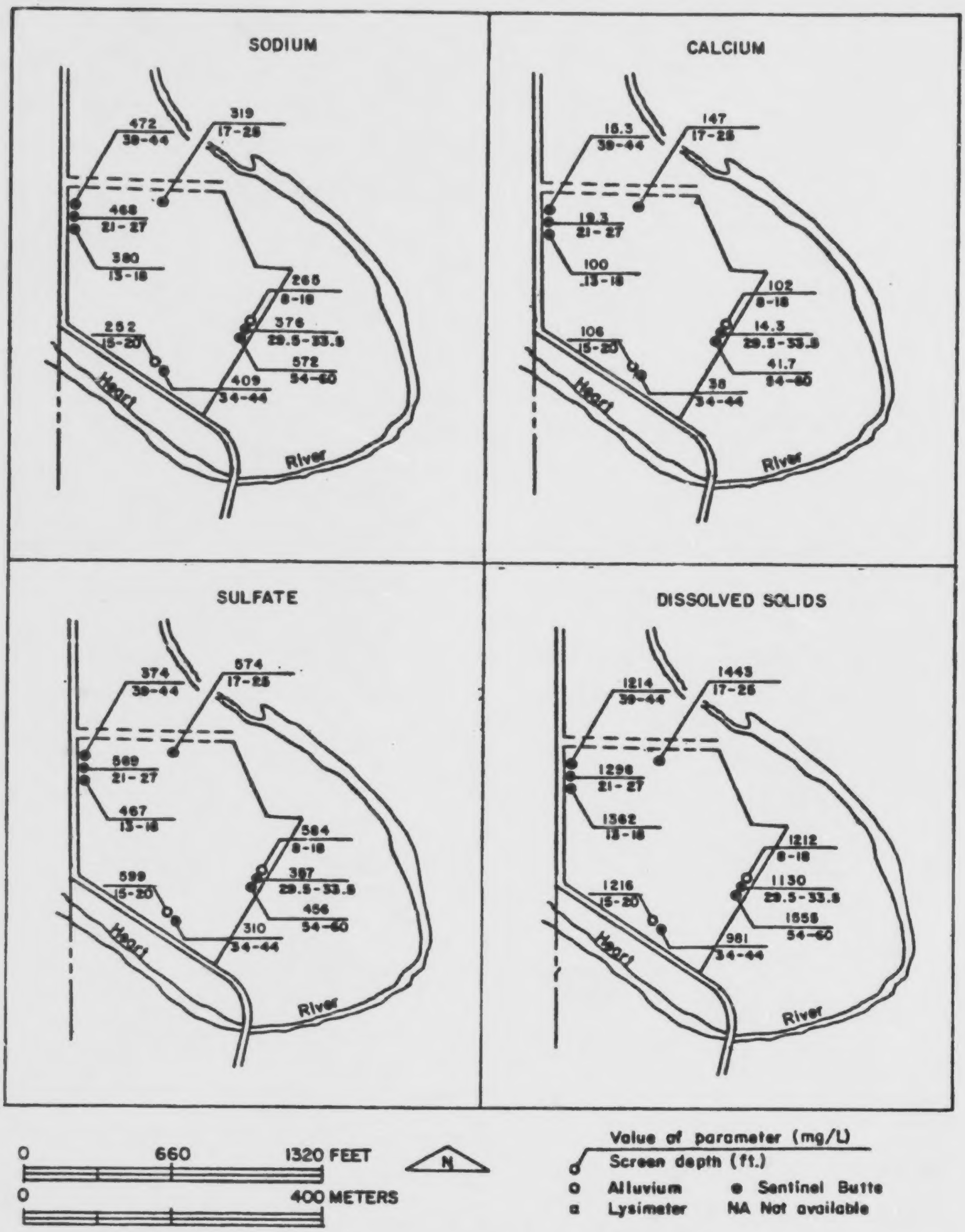

SODIUM
472
39-44
319
17-25
468
21-27
380
13-18
265
8-18
376
29.5-33.5
572
54-60
252
15-20
409
34-44
Heart
River
CALCIUM
18.3
39-44
147
17-25
19.3
21-27
100
13-18
102
8-18
14.3
29.5-33.5
41.7
54-60
106
15-20
38
34-44
Heart
River
SULFATE
374
39-44
574
17-25
569
21-27
467
13-18
584
8-18
387
29.5-33.5
456
54-60
599
15-20
310
34-44
Heart
River
DISSOLVED SOLIDS
1214
39-44
1443
17-25
1298
21-27
1362
13-18
1212
8-18
1130
29.5-33.5
1656
54-60
1216
15-20
981
34-44
Heart
River
0
660
1320 FEET
0
400 METERS
N
Value of parameter (mg/L)
Screen depth (ft.)
○ Alluvium
● Sentinel Butte
▫ Lysimeter
NA Not available

Figure 29. Control site groundwater constituents–selected parameters.

The average sodium, calcium, magnesium, sulfate, and dissolved solids concentrations of the lagoon effluent were 306, 55, 15, 359, and 1,202 mg/L, respectively. Results also showed that the concentrations of these parameters were lower in the Sentinel Butte aquifer than in the alluvium aquifer for the test site areas unaffected by lagoon leakage. In the area of the test site affected by lagoon leakage, concentrations of these parameters decreased and approached those for the lagoon effluent. Apparently the large amount of water leaking from the lagoon over the years has leached the bulk of the mineralized fractions from the soils.

Phosphorus--

The dissolved phosphorus concentrations in the test site and control site alluvium wells were generally just above or at minimum detectable levels by the analytical methods employed. The soluble phosphorus average concentrations at the test site and control site were 0.06 mg/L and 0.07 mg/L, respectively. Soluble orthophosphate phosphorus average concentrations were 0.03 and 0.05 mg/L at the test and control sites, respectively. Since the initial phosphorus of the irrigation effluent was from 3.0 to 10.2 mg/L, it appeared that the soil column provided a very effective means of phosphorus removal. This was supported by lysimeter data for phosphorus samples 224101, 224201, and 224301, which indicated that phosphorus removal was taking place over the upper soil horizon. However, the results were not quantitative due to evaporative effects in the lysimeter. It then became apparent that phosphorus had accumulated in the soil, a result to be discussed in more detail in the soil section.

Metals--

Groundwater was analyzed for the presence of arsenic, boron, cadmium, cobalt, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, and zinc. The concentrations of cadmium, cobalt, chromium, lead, mercury, and nickel were generally at or below minimum detectable levels. Boron was highly variable over the range of 0.1 to 1.4 mg/L for both sites (Appendix B).

Arsenic, copper, iron, manganese, selenium, and zinc had higher ranges and average concentrations at the test site than at the control site. The ranges of concentrations for these parameters in the effluent and in the alluvium wells at the control and test sites are given in Table 20. Variations in these parameters in the Sentinel Butte were generally in the same ranges as in the alluvium. The effluent concentrations were generally lower than those of the test site for each parameter. Effluent concentrations were either lower or in the same range of concentrations as in the control site.

Despite the high variability of metal parameters in the groundwater samples, the difference in concentrations could be attributed to varied soil characteristics. The test site soils were higher in total arsenic, copper, manganese, and zinc concentrations than the control site soils. Selenium concentrations in both sites were below minimum detectable ranges.

Pesticides and Herbicides--

The concentrations for lindane, 2,4-D, and 2,4,5 TP silvex in the control site wells ranged from <0.4 to 392 ng/L, <0.5 to 52.4 ng/L, and <0.2 to 272 ng/L, respectively. The concentrations for the same parameters at the

TABLE 20. RANGE OF CONCENTRATIONS OF SELECTED METALS IN THE EFFLUENT AND ALLUVIUM AQUIFER GROUNDWATERS (μg/L)

	Effluent	Alluvium Control	Alluvium Test
Arsenic	<5 - 11	<5 - 12	<5 - 62
Copper	<20 - 50	<20 - 50	<20 - 76
Iron	200 - 1,100	<200 - 1,000	200 - 6,600
Manganese	<50 - 90	<50 - 1,000	<50 - 1,900
Selenium	<10 - 13	<10	<10 - 78
Zinc	17 - 125	32 - 96	36 - 1,055

test site wells ranged from <0.4 to 82 ng/L, <0.5 to 76 ng/L, and <0.2 to 184 ng/L (Appendix B)

The average concentrations for lindane, 2,4-D, and 2,4,5 TP silvex at the control site were 53.6, 6.2, and 47.1 ng/L, respectively. The test site averaged 9.7, 8.7, and 33.7 ng/L, respectively (Table 10). Thus, there was no leakage of these indicator pesticides and herbicides through the soil column. The average effluent concentrations for lindane, 2,4-D, and 2,4,5 TP silvex were 397, 44, and 93 ng/L, respectively (Table 7). No trend in concentrations for any of these parameters was observed.

In analyses for pesticides at the test and control sites, endrin, methoxychlor, and toxaphene were below detectable limits.

SOILS

General

For many of the parameters investigated in the soil, the differences between the control and test sites were not significant at the 0.05 level, particularly at depths greater than 10 cm. Mean values and statistical analysis are presented in Table 21. The method of pooled variances was utilized to compare the means for the test site with those of the control site at the 0.05 level of significance. The upper three sampling depths (0-10 cm) were combined for analysis. Relative comparisons of total and extractable concentrations of elements between control and treatment sites and the normal expected ranges of the various elements in soils are shown in Figures 30 and 31.

Of the 38 soil parameters studied, 14 were significantly different at the 0.05 level for 0-10 cm depth (Table 21), while only 5 were significantly different for the 0-10 cm and 30 cm depths. For the 0-10 cm, 30 cm, and 100 cm depths, only one parameter was significantly different, and none were significatnly different for all depths, including 300 cm.

TABLE 21. SOIL MEANS FROM THE TEST AND CONTROL SITES

	Means (ug/g except where noted)							
	Depth: 0-10 cm		Depth: 30 cm		Depth: 100 cm		Depth: 300 cm	
	Test	Control	Test	Control	Test	Control	Test	Control
pH	7.7	7.3[a]	8.5	7.3[a]	8.6	8.6	8.6	8.4
Inorganic N	41.3	37.7	24.3	28.0	29.4	18.3	20.4	18.6
Total Organic N	2987	1726	768	545	395	359	222	274
Total Phosphorus	778	622[a]	574	529	554	565	450	459
Available Phosphorus	90	87	30	46	14	18	6	11
Total Sulfur	355	292	264	200	243	176	171	156
Cation Exchange Capacity (meq/100g)	22	12[a]	16	10[a]	13	9	10	10
Extractable Aluminum	18	35	4	57	4	24	3	17
Extractable Boron	1.91	1.45	1.02	0.87[a]	0.94	0.69[a]	0.67	0.63
Extractable Cadmium	0.04	0.03	0.20[b]	0.02[b]	0.02[b]	0.03	0.02[b]	0.03
Extractable Cobalt	0.22	0.36	0.16	0.16	0.18	0.19	0.17	0.12[b]
Extractable Chromium	0.02[b]	0.02[b]	0.02[b]	0.02[b]	0.02[b]	0.02[b]	0.02[b]	0.02[b]
Extractable Copper	4.2	1.5[a]	1.9	1.1	3.3	1.7	3.4	3.1
Extractable Iron	50	44	28	36	33	27	36	29
Extractable Lead	1.2[b]	1.2[b]	1.2[b]	1.2[b]	1.2[b]	1.2[b]	1.2[b]	1.2
Exchangeable Magnesium (mg/g)	0.82	0.65[a]	0.76	0.55	0.90	0.54[a]	0.66	0.61
Extractable Manganese	29	31	20	20	20	19	19	18
Extractable Nickel	1.1	0.9	0.7	0.9	0.7	0.9	0.6	1.0
Exchangeable Potassium (mg/g)	0.6	0.30[a]	0.3	0.3	0.2	0.2	0.2	0.1
Exchangeable Sodium (mg/g)	0.72	0.30[a]	0.57	0.25[a]	0.56	0.29[a]	0.39	0.33
Extractable Zinc	5.17	5.69	0.20	1.94[a]	1.25	0.47	1.25	0.87
Total Aluminum (mg/g)	43	31	48	38	48	39	44	35
Total Cadmium	2[b]	2[b]	2[b]	2[b]	2[b]	2[b]	2[b]	2[b]
Total Calcium (mg/g)	3.0	3.2	5.3	3.1	6.3	4.9	7.0	5.9
Total Cobalt	4.9	3.7	4.7	3.1	5.5	5.0	4.4	3.8
Total Chromium	35	27[a]	32	31	34	32	31	30
Total Copper	16.8	8.5[a]	14.0	8.6[a]	16.3	12.0	13.0	12.7
Total Iron (mg/g)	10.2	8.5	8.9	8.3	9.6	9.1	9.5	8.3
Total Lead	10[b]	10[b]	10[b]	10[b]	10[b]	10[b]	10[b]	10[b]
Total Magnesium (mg/g)	6.0	5.2	6.0	4.6	6.3	5.2	5.5	5.1
Total Manganese	301	209[a]	248	203	277	254	238	213
Total Mercury	0.05[b]	0.05[b]	0.05[b]	0.05[b]	0.05[b]	0.05[b]	0.05[b]	0.05[b]
Total Nickel	15.1	8.8[a]	15.3	12.0	14.3	12.7	14.3	12.1
Total Potassium (mg/g)	5.5	6.4[a]	5.5	6.2	5.5	6.2	5.2	5.6
Total Sodium (mg/g)	10.3	11.8[a]	11.0	11.6	10.5	12.0	11.6	11.2
Total Zinc	83	68	67	59	74	63	66	60
Total Arsenic	7	4[a]	6	5[a]	6	5	6	6
Total Selenium	1[b]	1[b]	1[b]	1[b]	1[b]	1[b]	1[b]	1[b]

[a] Test and control sites significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

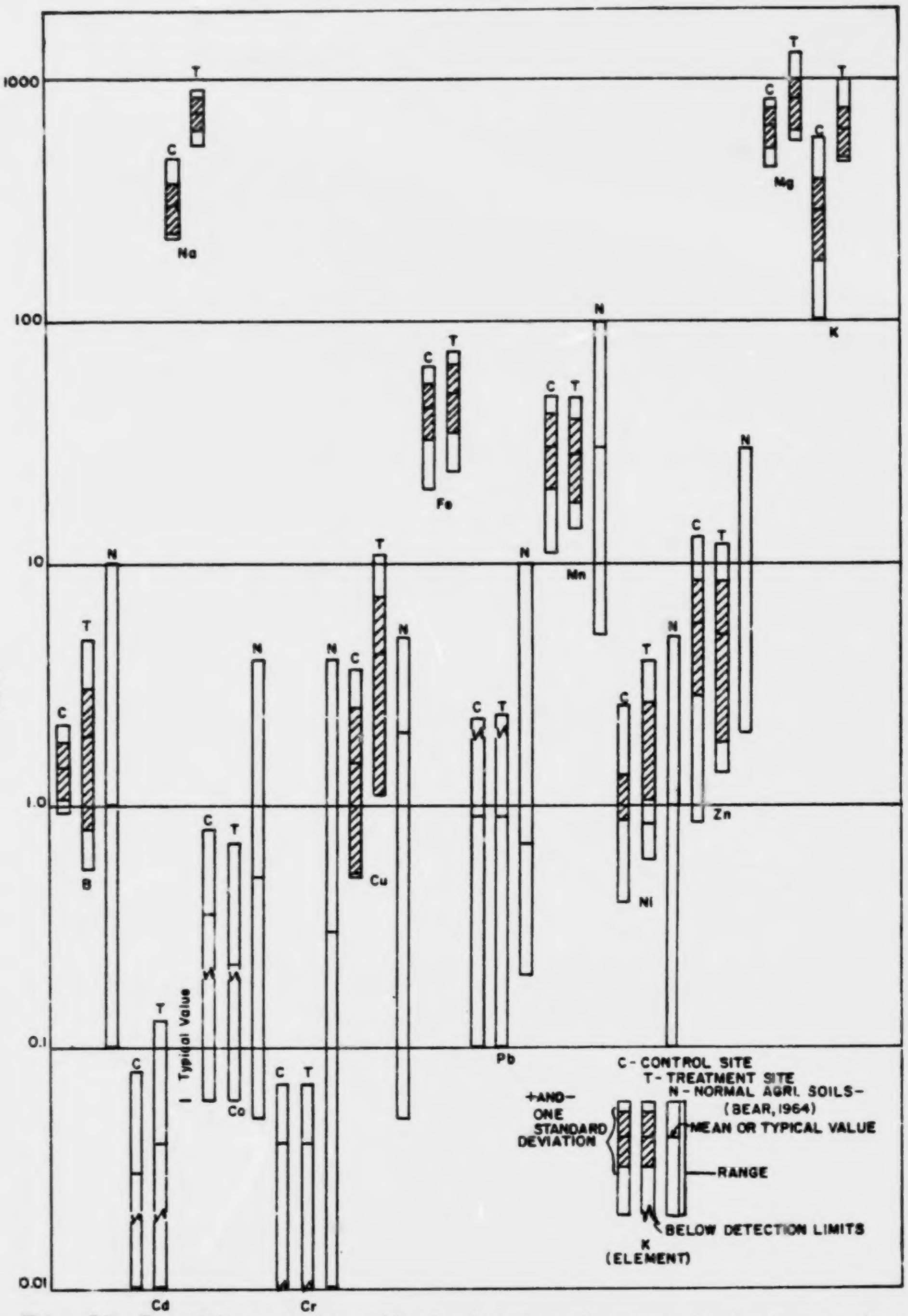


Figure 30. Extractable or exchangeable chemical element concentration levels for surface soils (0-10 cm) in control site, treatment site, and normal agriculture soils.

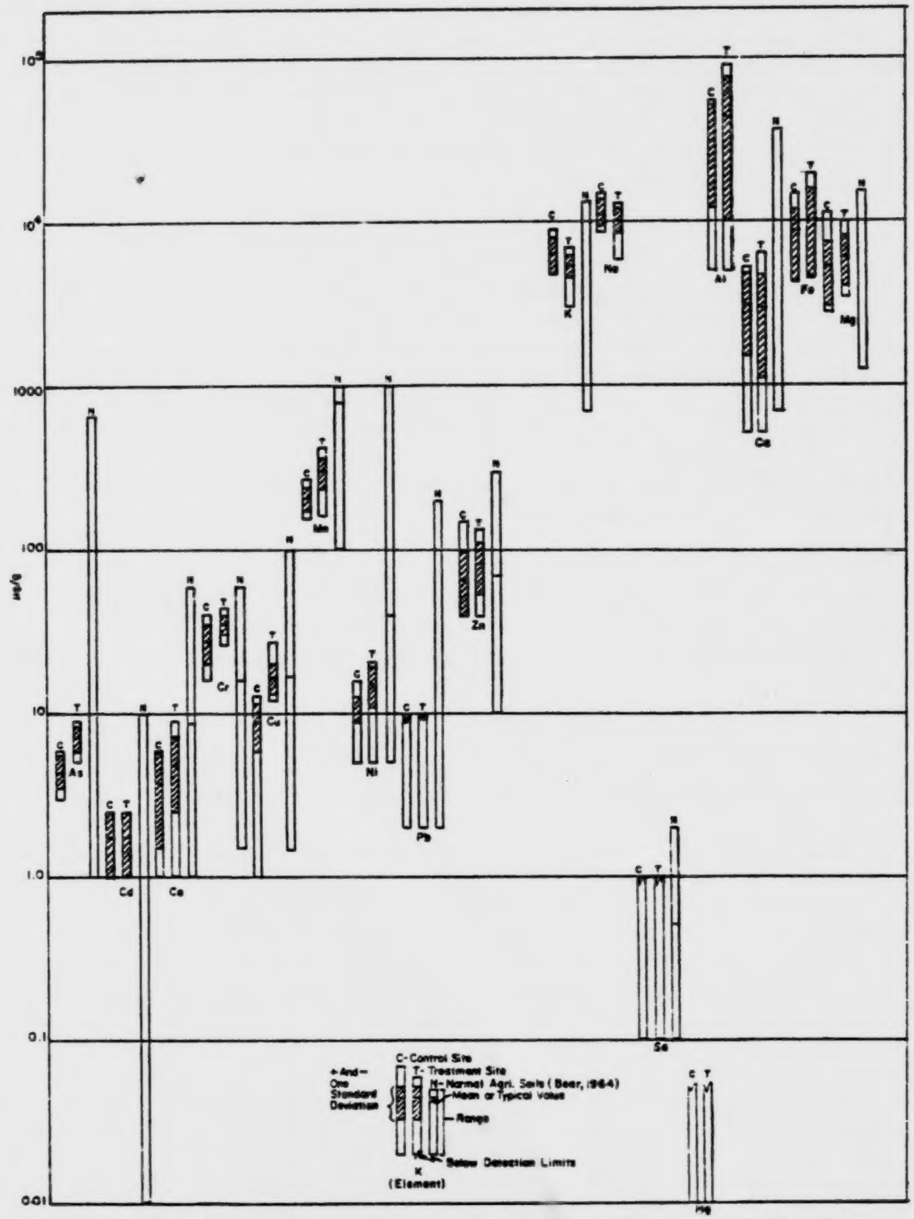


Figure 31 : Total chemical element concentration levels for surface soils (0-10 cm) in control site, treatment site, and normal agriculture soils.

Metals (Extractable and Exchangeable)--

For many of the extractable and exchangeable metals in the soil, there were either no differences between the control and test site samples, or quantities were below detectable limits. Magnesium showed a generally consistent reduction of 0.2 to 0.3 mg/g on both control and test sites between August, 1976, and November, 1976. The uptake of this metal by plants with roots that penetrated all but the deepest samples may have been one of the factors accounting for this difference. This same pattern also holds for total magnesium samples from both sites. Sodium and potassium generally followed similar patterns at both sites and had values within normal ranges expected for soils of this type.

The statistical analyses (Table 21) indicated that mean concentrations for extractable copper and for exchangeable potassium, sodium, and magnesium were significantly greater for the 0-10 cm depth in the soil of the test site than in that of the control site. The analyses also showed mean concentrations for extractable boron and exchangeable sodium to be significantly greater while extractable zinc was significantly less at the 0.05 level for test site soils than for the soils to the 30-cm depth in the control site. For the 100 cm depth, mean values for extractable boron and exchangeable magnesium and sodium were significantly greater in the test site than in the control site. At the 300 cm depth no significant differences were found for any exchangeable or extractable metals.

Metals (Total)--

Copper in the test site soils had an average difference of 5.5 μg/g over that found in the control site soils across the entire soil profile. Significant differences were found for total copper in the 0-10 cm and 30 cm depth ranges (Table 21).

Total arsenic found in the test site had a consistent difference of approximately 1.7 μg/g over that in the control site. Significant differences for arsenic occurred in the 0-10 cm and 30 cm depth ranges.

For manganese and zinc, large consistent differences were found at various depths. A more detailed analysis is presented in following sections. The mean concentrations for total chromium and nickel in the 0-10 cm depth were found to be significantly greater at the test site than at the control site. Potassium and sodium concentrations in the 0-10 cm depth were found to be significantly greater at the the control site than at the test site. However, differences were not significant at the 30, 100, and 300 cm depths.

Phosphorus--

Soil analyses showed test site soils to contain significantly greater concentration of total phosphorus than control site soils at the 3 and 10 cm depths (Table 22). In surface soils and at depths $\geq$ 30 cm, there were no statistically significant differences in total phosphorus concentration between the control and test sites. This indicated that the soil was an effective trap for phosphorus. Using the statistically significant differences, the excess amount of total phosphorus that had accumulated at the test

TABLE 22. ACCUMULATION OF TOTAL PHOSPHORUS (P) IN THE SOIL (μg/g)

Depth = 0 cm		Depth = 3 cm[a]		Depth = 10 cm[a]		Depth = 30 cm		Depth = 100 cm		Depth = 300 cm	
Sample No.	P	Sample No.	P	Sample No.	P	Sample No.	P	Sample No.	P	Sample No.	P
Control Site											
21111	563	21112	561	21113	548	21114	530	21115	554	21116	403
21131	908	21132	540	21133	485	21134	601	21135	545	21136	452
21211	608	21212	597	21213	575	21214	489	21215	518	21216	605
21231	664	21232	667	21233	682	21234	445	21235	481	21236	421
21311	590	21312	513	21313	462	21314	574	21315	513	21316	483
21331	757	21332	713	21333	767	21334	536	21335	776	21336	387
$\bar{x}$ =	682	$\bar{x}$ =	599	$\bar{x}$ =	587	$\bar{x}$ =	529	$\bar{x}$ =	565	$\bar{x}$ =	459
Test Site											
22111	841	22112	719	22113	680	21114	508	22115	447	22116	450
22131	1108	22132	999	22133	675	21134	604	22135	513	22136	515
22211	806	22212	683	22213	669	22214	594	22215	604	22216	403
22231	768	22232	699	22233	783	22234	541	22235	555	22236	371
22311	705	22312	665	22313	723	22314	539	22315	607	22316	459
22331	826	22332	819	22333	832	22334	659	22335	600	22336	499
$\bar{x}$ =	842	$\bar{x}$ =	764	$\bar{x}$ =	727	$\bar{x}$ =	574	$\bar{x}$ =	554	$\bar{x}$ =	450

[a] Mean differences at these depths statistically significant with a 0.05 level of confidence.

$\bar{x}$ = means.

site over the control site, at the 3 and 10 cm depths, was calculated to be 408 kg/ha (363 lb/acre).

The phosphorus concentration of the groundwater leaving both sites was low and similar to that of the control site irrigation water, but could account for approximately 12 kg/ha (10.7 lb/acre) during the 17 year period of operation. During the same period approximately 34 kg/ha (31 lb/acre) of phosphorus in the form of barnyard manure was applied while 180 kg/ha (161 lb/acre) was removed by the crops at each site.

The average phosphorus concentration of the waterwater was 6.9 mg/L as compared to only 0.05 mg/L in the control site irrigation water. The phosphorus applied at an irrigation rate of 140 cm (55 in.) per year for 17 years was 1631 kg/ha (1451 lb/acre) at the test site as compared to only 11.8 kg/ha (10.5 lb/acre) at the control site.

An attempted phosphorus balance for the test site is shown.

Applied Wastewater & Fertilizer		Removed Cropping and Ground water		Excess Retained in Soils		Unaccounted For
1665 kg/ha	-	192 kg/ha	-	408 kg/ha	=	1065 kg/ha

Although 1065 kg/ha remain unaccounted for, the exercise does show that excess phosphorus has been applied to and accumulated in the test site surface soils, and that there is presently no apparent phosphorus movement below approximately 40 cm.

Manganese--

Comparison of the total manganese soil sample means for test and control sites showed statistically significant differences at the upper soil depths (0, 3, and 10 cm) but not at depths ≥30 cm (Table 23). As previously shown for other elements, the soil served as an effective trap for this metal down to the 10 cm depth. At this depth, the test site had an average of 92 μg/g (122 kg/ha or 109 lb/acre) of manganese over the control site.

Values for five lagoon effluent samples were highly variable for manganese. Assuming a 0.05 mg/L average for manganese applied to the land through wastewater irrigation, the total manganese applied was calculated to be approximately 11.9 kg/ha (10.6 lb/acre).

Assuming 78 μg/g of manganese in the test site plants and an average annual crop yield of 3920 kg/ha, approximately 5.2 kg/ha has been removed from the test site by cropping over the past 17 years.

The one analysis of the control site irrigation water showed 0.23 mg/L manganese which calculated to 54.7 kg/ha of total manganese applied while 3.5 kg/ha was removed by cropping. This indicates that the excess manganese found in the test site soils did not come from the wastewater.

TABLE 23. ACCUMULATION OF MANGANESE IN THE SOIL ($\mu g/g$)

Depth = 0 cm[a]		Depth = 3 cm[b]		Depth = 10 cm[a]		Depth = 30 cm		Depth = 100 cm		Depth = 300 cm	
Sample No.	Mn	Sample No.	Mn	Sample No.	Mn	Sample No.	Mn	Sample No.	Mn	Sample No.	Mn
Control Site											
21111	234	21112	248	21113	221	21114	226	21115	273	21116	228
21211	153	21212	169	21213	198	21214	179	21215	243	21216	276
21311	202	21312	198	21313	202	21314	238	21315	224	21316	221
21131	228	21132	228	21133	260	21134	212	21135	281	21136	251
21231	178	21232	218	21233	170	21234	194	21235	194	21236	156
21331	210	21332	271	21333	170	21334	167	21335	308	21336	148
$\bar{x}$ =	201	$\bar{x}$ =	222	$\bar{x}$ =	204	$\bar{x}$ =	203	$\bar{x}$ =	254	$\bar{x}$ =	213
Test Site											
22111	321	22112	320	22113	338	22114	280	22115	221	22116	221
22211	308	22212	290	22213	364	22214	271	22215	386	22216	243
22311	299	22312	318	22313	355	22314	304	22315	320	22316	205
22131	159	22132	324	22133	425	22134	283	22135	255	22136	301
22231	343	22232	282	22233	239	22234	180	22235	194	22236	131
22331	300	22332	255	22333	175	22334	167	22335	287	22336	328
$\bar{x}$ =	288	$\bar{x}$ =	298	$\bar{x}$ =	316	$\bar{x}$ =	248	$\bar{x}$ =	277	$\bar{x}$ =	238

---

[a] Significant difference with a 0.02 level of confidence.

[b] Significant difference with a 0.01 level of confidence.

$\bar{x}$ = means.

Zinc--

The amount of zinc applied to the test site in the effluent averaged 0.05 mg/L for five samples collected from the storage lagoon during the course of the study. Based on this effluent average value, 11.9 kg/ha (10.6 lb/acre) had been applied to the test site over the past 17 years. Because of changing detection limits between rounds, the one sample of control site irrigation water was measured at less than a detectable limit of 0.05 mg/L. It is probable that some zinc was also added to the control site and that 11.9 kg/ha is more than the actual additional load to the test site. An attempt was made to account for this zinc by comparing test and control site soil samples taken at various depths. Results are shown in Table 24. With the possible exception of surface samples, the test site showed more zinc than the control site at all depths. However, only the 31 μg/g difference found at 3 cm (1.2 in) was statistically significant. If the zinc trapped at the 3 cm depths were spread evenly over the 0-10 cm depths, a conservative estimate of 15 μg/g/cm could be obtained for use in the calculation used to balance the amount of zinc applied with the wastewater. Using this figure, a value of 18.8 kg/ha (16.7 lb/acre) was reached, which was slightly more than the amount of zinc (11.9 kg/ha or 10.6 lb/acre) applied with the wastewater. Assuming 37 and 22 μg/g of zinc as found in the test and control site plants and an average annual crop yield of 3,920 kg/ha (3,500 lb/acre), approximately 2.5 kg/ha has been removed from the test site in crop harvests over the past 17 years while 1.5 kg/ha has been removed from the control site soils. The excess zinc may not all be attributable to wastewater irrigation.

Organic Nitrogen--

Although it appeared from sample results that at most depths there was more total organic nitrogen at the test site than at the control site, this conclusion could not be supported by statistical analysis. No significant differences occurred at any depth, even though the differences in sample means were quite large. Apparently, the high variability between subsamples at the control site as well as the test site precludes obtaining a statistically significant difference.

The observed increase in nitrogen concentration of the test site soils has been used to calculate the nitrogen balance for the 17-year irrigation system. This will be presented in a later section of this report.

PLANTS

The grass crop was sampled during the study at both the control and test sites in June and again in November of 1976.

The 27 parameters studied in the brome grass crop at the test and control sites are shown in Table 25 together with the normal range of concentrations for these parameters in grass crops.

From the limited data available, the following observations can be made regarding the relative performance of the control and test site grass crops.

Though phosphorus concentrations were similar at both sites, mean con-

TABLE 24. ACCUMULATION OF ZINC IN THE SOIL (μg/g)

Depth = 0 cm		Depth = 3 cm[a]		Depth = 10 cm		Depth = 30 cm		Depth = 100 cm		Depth = 300 cm	
Sample No.	Zn	Sample No.	Zn	Sample No.	Zn	Sample No.	Zn	Sample No.	Zn	Sample No.	Zn
Control Site											
21111	92	21112	58	21113	60	21114	62	21115	76	21116	70
21131	151	21132	59	21133	-	21134	63	21135	54	21136	74
21211	113	21212	55	21213	77	21214	53	21215	88	21216	72
21231	55	21232	58	21233	45	21234	43	21235	43	21236	34
21311	39	21312	52	21313	91	21314	93	21315	81	21316	75
21331	47	21332	58	21333	43	21334	42	21335	38	21336	32
$\bar{x}$ =	83	$\bar{x}$ =	57	$\bar{x}$ =	63	$\bar{x}$ =	59	$\bar{x}$ =	63	$\bar{x}$ =	60
Test Site											
22111	118	22112	108	22113	92	22114	82	22115	73	22116	82
22131	40	22132	61	22133	64	22134	58	22135	54	22136	58
22211	99	22212	108	22213	106	22214	87	22215	98	22216	87
22231	79	22232	57	22233	57	22234	36	22235	46	22236	36
22311	88	22312	128	22313	133	22314	100	22315	121	22316	78
22331	62	22332	62	22333	39	22334	37	22335	52	22336	53
$\bar{x}$ =	81	$\bar{x}$ =	87	$\bar{x}$ =	82	$\bar{x}$ =	67	$\bar{x}$ =	74	$\bar{x}$ =	66

[a] Mean difference at this depth statistically significant with a 0.05 level of confidence.

$\bar{x}$ = means.

TABLE 25. MEAN CONCENTRATIONS OF PARAMETERS IN TEST AND CONTROL SITE PLANT LEAVES

Parameter	Means ($\mu g/g$ unless noted)		
	Control	Test	Normal Range[c]
Ammonium-N	221	380	--
Total Organic N (mg/g)	19	15	27-35
Nitrite + Nitrate-N	649	1014	--
Total Phosphorus (mg/g)	2.7	2.7	2-4
Total Sulfur	1213	1074	1000-3000
Total Arsenic	1[b]	1[b]	--
Total Boron	14.1	19.6	10-100
Total Cadmium	5[b]	5[b]	0.01-1.0
Total Calcium (mg/g)	3.3	3.6	4-10
Total Cobalt	1[b]	1[b]	1-50
Total Chromium	2	5[a]	1-100
Total Copper	7.4	6.8	2-100
Total Lead	5[b]	5[b]	0.1-10
Total Magnesium (mg/g)	1.3	1.3	2-4
Total Manganese	53	78[a]	5-500
Total Mercury	0.05[b]	0.05[b]	0.01-1.0
Total Nickel	0.5[b]	0.5[b]	1-100
Total Potassium (mg/g)	5.1	4.3	17-25
Total Sodium (mg/g)	1.2	3.1[a]	100-500
Total Zinc	22	37[a]	10-300
Total Selenium	1[b]	1[b]	--
Endrin (ng/g)	0.03[b]	0.03[b]	--
Lindane (ng/g)	0.5	0.9	--
Methoxychlor (ng/g)	0.01[b]	0.01[b]	--
Toxaphene (ng/g)	0.1[b]	0.1[b]	--
2,4-D (ng/g)	10.4	15.4	--
2,4,5 TP Silvex (ng/g)	6.6	7.0	--

[a] Test and control sites significantly different at the 0.05 level.

[b] Concentrations below detection limit indicated.

[c] Bear, 1964, and Walsh, 1973.

centrations for chromium, manganese, sodium, and zinc were found to be significantly greater at the 0.05 level for the test site than for the control site. The increased plant concentrations of chromium, manganese, and zinc may be related to the higher concentrations of these parameters found in the test site soils. However, sodium was found at higher concentrations in the control site soils. Of these parameters, only zinc occurred at higher concentrations in the wastewater than in the control site irrigation water. No significant difference was observed for the remaining parameters (Table 25).

Although many of the crop parameters had highly variable analytical results, mean values for all parameters were well within the normal range for grass crops.

The complete crop analytical results are presented in Appendix B.

COLIFORM BACTERIA

As anticipated, the river water and lagoon effluent samples gave positive results for the presence of coliform bacteria and, in most cases, fecal coliform bacteria. Two samples of the municipal water supply resulted in one positive coliform count.

Of the wells at the control site, one showed positive coliform bacteria twice, seven showed positive once, and one was never positive.

Of the wells at the test site, positive coliform bacteria counts were obtained once from seven wells, twice from three wells, and four times from well 22080. All negative counts were obtained from five wells and three lysimeters.

There was no pattern with respect to depth or well location at either the test or control site that would suggest coliform had actually reached the groundwater aquifer. Of the positive counts obtained, 7 of the 9 on the control site and 6 of the 17 on the test site occurred on the second sampling round.

Although all wells were disinfected during construction and prior to sampling (see Section 6), one would assume that well 22080 was contaminated in some way, perhaps during construction. The well was located at the south end of the test site and completed in the Sentinel Butte Formation at a depth of 23 m (75 ft).

It was significant that no wells showed positive fecal coliform counts and that most wells at various depths and on various rounds of data collection were also negative for coliform bacteria.

Plant samples from all sub-areas on both control and test sites showed positive coliform bacteria on either the first or second round of data collection. Fecal coliform bacteria were also present on both control and test site plants. Since both sites are used for pasture by cattle, this result is not surprising, even though plant samples were washed prior to analysis.

INTERACTIONS OF WATER, SOILS, AND PLANTS

Necessarily, each of the parameters in this study had to be isolated for data analysis and interpretation. However, in addition to the significance attributable to individual components of an ecosystem, the interactions of the various parameters are also significant. The physical components of the system (i.e., geology, hydrology, topography, etc.), comprise the structural framework for the development of the soil and the later biological components (i.e., bacteria, plants, soil organisms, and other animals).

The application of wastewater with inherent constituents to the land may be regarded as an energy input to the ecosystem, resulting not only in enhanced plant growth, but adding a potential for diversity in species composition of the biota. The resulting enriched and improved environment is often overlooked by those whose primary focus is the potential health hazards often associated with use of sewage effluent.

Chemicals in the wastewater interact with one another and with soil particles at the air-soil interface. Several processes may occur here simultaneously, such as oxidation, nitrification, denitrification, evaporation, and adsorption. As the water percolates through the soil, the physical and chemical characteristics of the soil determine the fate of each element in its downward migration. Available surface area of soil particles along with the chelating property of resident molecules combine to assist the distribution and abundance of the chemical species in the soil profile.

In a natural as well as an agricultural system, the results of the above interactions of soil and water influence the growth and development of plants. Major nutrients required for plant growth, such as nitrogen and phosphorus, as well as such trace elements as manganese or zinc are included as constituents in wastewater. For the proper design and management of wastewater irrigated land, it is essential that these various interactions be taken into consideration. Mismanagement could result in a breakdown of natural processes and barriers that lead to crop failures, lower crop yields, or, more importantly, the appearance of toxic elements, viruses, or coliform organisms in groundwater. As indicated in several sections of this report, the land treatment system at Dickinson has experienced few such negative occurrences.

PROJECTED USEFUL LIFE OF SITE FOR WASTEWATER IRRIGATION

The intent of this study was to provide answers to a number of questions relating to the long-term viability of land application as a treatment system. Two such questions discussed in the following paragraphs are:

1. For how long a period can a land application system be expected to provide satisfactory treatment for wastewater?
2. What effect does continued long-term application of organic, nitrogenous, and heavy metal constituents have on the soil and crop system?

For a projection of 100 years useful life, the phosphorus applied to the test site each year is 98 kg/ha (87 lb/acre) minus the harvest of 10.6 kg/ha (9.5 lb/acre) or 86 kg/ha (77 lb/acre), thus making the total prospective load 8,600 kg/ha/100 yr (7,700 lb/acre). If all the phosphorus was eventually held as the stable hydroxyapatite, this would require 16,350 kg/ha (14,600 lb/acre) of calcium or 40,880 kg/ha (36,500 lb/acre) of calcium carbonate. If only half the total calcium shown in the Dickinson profile was calcium carbonate (a very conservative assumption), the reserve in the top 100 cm (39 in) of an acre would be 25,500 kg (56,000 lb) of calcium carbonate, which would provide approximately twice the required amount. The fact that no firm indication existed for an accumulation of phosphorus below 40 cm (16 in) was also reassuring. This layer alone has proved to be a sufficient trap for the added phosphorus over a period of 17 years.

Using the mean differences, as opposed to the statistically significant differences used earlier, the excess accumulation of nitrogen, phosphorus, and zinc in the test site soils compared to the control site soils was calculated. This was compared to the additional loading resulting from wastewater irrigation.

The additional organic nitrogen loading was calculated to be 4,100 kg/ha (3,670 lb/acre) for soil 0 to 40 cm (16 in) in depth. The additional inorganic nitrogen loading was calculated to be nonexistent. The 17-year projected application of nitrogen due to effluent was approximately 2,780 kg/ha (2,480 lb/acre) and due to synthetic fertilizer was 270 kg/ha (240 lb/acre). Cropping accounts for 1,200 kg/ha (1,070 lb/acre), and nitrogen exiting the test site accounts for 220 kg/ha (200 lb/acre). Total nitrogen input was approximately 3,050 kg/ha (2,720 lb/acre). Total nitrogen either at the test site or that which has left the test site was 4,320 kg/ha (3870 lb/acre). The excess accumulation is unaccounted for.

The excess phosphorus in the test site soils was 520 kg/ha (460 lb/acre) versus 1,619 kg/ha (1,631-11.8) applied in the effluent over 17 years. The excess zinc measured in the test site soils was 71 kg/ha (63 lb/acre) versus less than 11.9 kg/ha (10.6 lb/acre) applied in the effluent over 17 years. The excess manganese measured in the test site soils was 320 kg/ha (290 lb/acre) versus 11.9 kg/ha (10.6 lb/acre) applied in the effluent over 17 years. This compares to 54 kg/ha (48 lb/acre) applied to the control site.

It can thus be concluded that an accurate accounting of the mass balances for the amounts of these parameters added in the effluent is not possible due to unknown variations in the quantities for each parameter over the 17-year period of effluent irrigation. In addition, the soils at the test and control sites may have native differences in amounts of the parameters, and calculations of amounts added in the effluent could never explain these differences.

Suggested mass application rates for low capacity soils are given in the Environmental Protection Agency's Process Design Manual for Land Treatment of Municipal Wastewater. Corresponding parameter concentrations that would allow 100-year loading of 140 cm/yr (4.58 ft/yr) and the mean concentrations of Dickinson's effluent are shown in Table 26.

Dickinson soils would have greater capacities to retain trace elements; however, Table 26 shows that for an effluent concentration of 0.921 mg/L, only boron at 1,139 lb/acre would exceed the recommended loading after 100 years of operation.

TABLE 26. SUGGESTED MAXIMUM APPLICATIONS OF TRACE ELEMENTS TO SOILS WITHOUT FURTHER INVESTIGATION[a]

Element	Mass application to soil, lb/acre[b]	Typical concentration, mg/L[c]	Effluent concentration, mg/L
Aluminum	4080	3.5	0.5
Arsenic	82	0.7	0.006
Boron	610	0.5[d]	0.92
Cadmium	8	0.007	0.01[e]
Chromium	82	0.7	0.02[e]
Cobalt	41	0.035	0.02[e]
Copper	164	0.14	0.02[e]
Iron	4080	3.5	0.7
Lead	4080	3.5	0.1[e]
Manganese	164	0.14	0.05[e]
Nickel	164	0.14	0.05[e]
Selenium	16	0.014	0.007
Zinc	1640	1.4	0.05[e]

[a] Values were developed for sensitive crops on soils with low capacities to retain elements in available forms.

[b] USEPA, 1977.

[c] Based on reaching maximum mass application in 100 years at an annual application rate of 140 cm/yr (4.58 ft/yr).

[d] Boron exhibits toxicity to sensitive plants at values of 0.75 to 1.0 mg/L.

[e] Concentrations below detection limit indicated.

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APPENDIX A

WELL LOGS FOR CONTROL AND TEST SITES

DICKINSON, NORTH DAKOTA

Drill Hole Logs

Control Site

Hole T.H.-1

Date: 6-28-76 Type Rig: Rotary
Casing: 1 1/4 in. plastic to 14 ft.
Screen: 1 1/4 in. saw-cut plastic 14 to 19 ft.
Remarks: Drilled with air, sand pack 0-39 ft.

Log: Depth in Feet

0-2	Soil
2-5	Sand, fine, brown
5-8	Silt, gray-brown
8-10	Sand, fine to medium, clean, wet, brown, with some small gravel
10-37	Sand, fine to medium, silty, gray-brown, soft
37-39	Sand, fine, cemented and hard, Sentinel Butte Fm.

Hole T.H.-2

Date: 6-28-76 Type Rig: Rotary
Casing: 1 1/4 in. plastic to 14 ft.
Screen: 1 1/4 in. saw-cut plastic 14 to 19 ft.
Remarks: Drilled with air, sand pack bridged and then fill-in screened section probably not sand packed.

Log: Depth in Feet

0-1	Soil
1-5	Sand, very fine, silty
5-6	Silt, sandy
6-8	Sand, medium
8-9	Sand, yellow-brown, cemented, Sentinel Butte Fm.
9-12	Sand, yellow brown, hard

12-25	Sand, fine, gray, soft, clean
25-29	Sand, fine, hard, blowing water
29-60	Sand, fine, soft, gray

Hole 21010

Date: 7-22-76 Type Rig: Rotary
Casing: 4 in. plastic to 54 ft.
Screen: 4 in. slotted (.016 in.) plastic 54 to 60 ft.
Remarks: Drilled with clear water, sand pack 52 to 60 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-10	Sand, fine
10-11	Sand, medium to coarse, few small gravel
11-15	Sand, fine with gravel at base
15-18	Clay, silty, gray
18-20	Sand, fine
20-25	Clay, silty and sandy
25-36	Sand, very fine, gray
36-38	Sand, silty with clay lenses, tight, Sentinel Butte Fm.
38-52	Sand, fine, dark gray to blue
52-54	Sand, very fine to fine, moderately cemented, white
54-60	Sand, very fine to fine, dark gray

Hole 21020

Date: 7-22-76 Type Rig: Rotary
Casing: 4 in. plastic to 29.5 ft.
Screen: 4 in. slotted (.016 in.) plastic 29.5 to 33.5 ft.
Remarks: Drilled with clear water, sand pack 28 to 34.5 ft., hole sealed with granular bentonite, screen air developed for 25 min.

Log: Depth in Feet

0-2.5	Soil
2.5-11	Sand, fine, brown, with coal fragments
11-13	Gravel and medium sand
13-20	Sand, blue, with scattered gravel
20-29	Clay, silty, with very fine sand lenses
30-34	Sand, very fine, blue, Sentinel Butte Fm.
34	Sand, well cemented, hard

Hole 21030

Date: 7-22-76 Type Rig: Rotary
Casing: 4 in. plastic to 8 ft.
Screen: 4 in. slotted (.016 in.) plastic 8 to 18 ft.

Remarks: Drilled with clear water, sand pack 6 to 18 ft., hole sealed with granular bentonite, screen air developed for 15 min.

Log: Depth in Feet

0-3	Soil
3-11	Sand, fine, brown, with coal and lignite fragments
11-19	Sand, fine to medium, with scattered gravel
19-20	Clay, silty, sandy, gray

Hole 21040

Date: 7-22-76 Type Rig: Rotary
Casing: 4 in. plastic to 34 ft.
Screen: 4 in. slotted (.016 in.) plastic 34 to 44 ft.
Remarks: Drilled with clear water, sand pack 31 to 44 ft., hole sealed with granular bentonite, screen air developed for 10 min.

Log: Depth in Feet

0-3	Soil
3-9	Sand, fine, brown
9-13	Sand, medium to coarse, scattered gravel
13-22	Sand, very fine, blue, with clay streaks, and some gravel at base
22-24	Clay, sandy, silty
24-45	Sand, very fine to fine, silty and clay lenses, blue-gray, Sentinel Butte Fm.

Hole 21050

Date: 7-23-76 Type Rig: Rotary
Casing: 4 in. plastic to 15 ft.
Screen: 4 in. slotted (.016 in.) plastic 15 to 20 ft.
Remarks: Drilled with clear water, sand pack 12 to 25 ft., hole sealed with granular bentonite, screen air developed for 15 min.

Log: Depth in Feet

0-2	Soil
2-10	Sand, fine, with coal fragments and clay stringers
10-19	Sand, medium to coarse, with small gravel, gravel more common at base
19-23	Sand, fine, soft
23-25	Clay, silty and sandy

Hole 21060

Date: 7-23-76 Type Rig: Rotary
Casing: 4 in. plastic to 39 ft.
Screen: 4 in. slotted (.016 in.) plastic 39 to 44 ft.
Remarks: Drilled with clear water, sand pack 35 to 45 ft., hole sealed with granular bentonite, screen air developed for 10 min.

Log: Depth in Feet

0-3	Soil
3-8	Sand, fine, with clay, medium sand near base
8-11	Sand, fine, yellow to brown, moderate cement, Sentinel Butte Fm.
11-14	Sand, fine, silty, blue-gray
14-15	Sand, clayey and silty, blue-gray
15-26	Sand, fine, blue-gray
26-28	Clay, silty, gray
28-45	Sand, very fine, soft, gray, with cemented lenses near base

Hole 21070

Date: 7-23-76 Type Rig: Rotary
Casing: 4 in. plastic to 21 ft.
Screen: 4 in. slotted (.016 in.) plastic 21 to 27 ft.
Remarks: Drilled with clear water, sand pack 20 to 27 ft., hole sealed with bentonite, screen air developed for 20 min.

Log: Depth in Feet

0-2	Soil
2-9	Sand, medium to coarse, with small gravel, clay pods and coal fragments
9-12	Sand, fine, yellow-brown, moderate cement, Sentinel Butte Fm.
12-27	Sand, fine, blue-gray, clay stringers at top and cemented stringers at base

Hole 21080

Date: 7-23-76 Type Rig: Rotary
Casing: 4 in. plastic to 13 ft.
Screen: 4 in. slotted (.016 in.) plastic 13 to 18 ft.
Remarks: Drilled with clear water, sand pack 12 to 20 ft., hole sealed with granular bentonite, screen air developed 20 min.

Log: Depth in Feet

0-2	Soil
2-11	Sand, fine, becomes medium to coarse with small gravel at base
11-12	Sand, fine, yellow-brown, moderate cement, Sentinel Butte Fm.
12-20	Sand, fine, blue-gray

Hole 21090

Date: 7-23-76 Type Rig: Rotary
Casing: 4 in. plastic to 17 ft.
Screen: 4 in. slotted (.016 in.) plastic 17 to 25 ft.
Remarks: Drilled with clear water, sand pack 15 to 25 ft., hole sealed with granular bentonite, screen air developed for 15 min.

Log: Depth in Feet

0-3	Soil
3-12	Sand, very fine, soft, becomes medium sand with gravel near base
12-14	Sand, fine, yellow-brown, moderate cement, Sentinel Butte Fm.
14-25	Sand, fine, blue-gray, with silty streaks

Hole 21150

Date: 7-26-76 Type Rig: Rotary
Casing: 4 in. plastic to 21.5 ft.
Screen: 4 in. slotted (.016 in.) plastic 21.5 to 29.5 ft.
Remarks: Drilled with clear water, sand pack 16 to 29.5 ft., sealed with granular bentonite, screen air developed for 15 min. Hole location downstream and across river from control irrigation site.

Log: Depth in Feet

0-2	Soil
2-12	Sand, fine, soft, with small to very small gravel, sand becomes medium to coarse with gravel at base
12-22	Clay, silty and sandy, gray, Sentinel Butte Fm.
22-30	Sand, fine, blue, cemented lense at top

Hole 21160

Date: 7-26-76 Type Rig: Rotary
Casing: 4 in. plastic to 6 ft.
Screen: 4 in. slotted (.016) plastic 6 to 12 ft.
Remarks: Drilled with clear water, sand pack 5 to 17 ft., hole sealed with granular bentonite, screen air developed for 15 min. Hole downstream and across river from control irrigation site.

Log: Depth in Feet

0-5	Soil
5-12	Sand, fine, medium to coarse toward base, with fine to medium gravel
12-17	Clay, sandy, silty, gray, Sentinel Butte Fm.

Test Sites

Hole T.H.-1

Date: 6-28-76
Casing: 1 1/4 in. plastic to 14 ft.
Screen: 1 1/4 in. saw-cut plastic 14 to 19 ft.
Remarks: Drilled with air, sand pack 0 to 20 ft.

Log: Depth in Feet

0-2	Soil
2-18	Sand, fine to medium, some silt, gray-brown, dry to 10 ft., moist below 10 ft.
18-20	Clay, gray, hard, dry, Sentinel Butte Fm.

Hole T.H.-2

Date: 6-28-76
Casing: 1 1/4 in. plastic to 29 ft.
Screen: 1 1/4 in. saw-cut plastic 29 to 39 ft.
Remarks: Drilled with air, sand pack 0 to 60 ft.

Log: Depth in Feet

0-1	Soil
1-3	Silt, with very fine sand
3-9	Sand fine to medium
9-12	Silt
12-17	Sand, fine to medium, wet
17-19	Sand, cemented, Sentinel Butte Fm.
19-54	Sand, very fine, silty, soft, blowing water at 45 ft., hard streaks beginning at 50 ft.
54-60	Sand, cemented, hard, blowing 5 gpm

Hole 22010

Date: 7-19-76 Type Rig: Rotary
Casing: 4 in. plastic to 37 ft.
Screen: 4 in. slotted (.016 in.) plastic 37 to 43 ft.
Remarks: Drilled with air to 12 ft., drilled remainder of hole with clear water, sand pack 36 to 45 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-2	Soil
2-20	Sand, fine, gray-brown, seep water at 8 ft., gravel at base
20-22	Clay, gray-white, sticky, Sentinel Butte Fm.
22-45	Sand, fine, soft, with coal fragments, cemented zone 35-36 ft.

Hole 22020

Date: 7-19-76 Type Rig: Rotary
Casing: 4 in. plastic to 18 ft.
Screen: 4 in. slotted (.016 in.) plastic 18 to 22 ft.
Remarks: Drilled with clear water, sand pack 16 to 23 ft., hole sealed with granular bentonite, used as pumping well in pump test.

Log: Depth in Feet

0-2	Soil
2-23	Sand, fine, silty, becomes fine to medium at base with gravel
23	Clay, gray-white, sticky, Sentinel Butte Fm.

Hole 22030

Date: 7-19-76 Type Rig: Rotary
Casing: 4 in. plastic to 45 ft.
Screen: 4 in. slotted (.016 in.) plastic 45 to 50 ft.
Remarks: Drilled with clear water, sand pack 39 to 60 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-1	Soil
1-15	Sand, fine, silty
15-17	Gravel, sand, fine to medium, dirty
17-24	Sand, fine, silty
24-37	Clay, gray-white, Sentinel Butte Fm.
37-39	Sand, very very fine, dark gray, cemented
39-45	Sand, clayey, very fine, soft
45-52	Sand, very fine, dark blue-gray, cemented yellow sand at 50 ft., hard
52-54	Clay, silty
54-60	Clay, gray, sticky

Hole 22040

Date: 7-20-76 Type Rig: Rotary
Casing: 4 in. plastic to 19 ft.
Screen: 4 in. slotted (.016 in.) plastic 19 to 24 ft.
Remarks: Drilled with clear water, sand pack 18 to 30 ft., hole sealed with granular bentonite

Log: Depth in Feet

0-2	Soil
2-13	Sand, fine, silty
13-15	Clay and gravel
15-18	Clay, silty
18-24	Sand, soft with cemented lenses, Sentinel Butte Fm.
24-30	Clay, sandy

Hole 22050

Date: 7-20-76 Type Rig: Rotary
Casing: 4 in. plastic to 13 ft.
Screen: 4 in. slotted (.016 in.) plastic 13 to 17 ft.
Remarks: Drilled with clear water, sand pack 12 to 17 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-2	Soil
2-11	Sand, fine
11-16	Sand, medium to coarse, gravel
16-17	Clay, sandy

Hole 22060

Date: 7-20-76 Type Rig: Rotary
Casing: 4 in. plastic to 49 ft.
Screen: 4 in. slotted (.016 in.) plastic 49 to 55 ft.
Remarks: Drilled with clear water, sand pack 47 to 55 ft., hole sealed with bentonite.

Log: Depth in Feet

0-2.5	Soil
2.5-15	Sand, very fine to fine, with gravel at base
15-16	Clay, sand and gravel, silty
16-29	Clay, Sentinel Butte Fm.
29-34	Clay, sandy
34-41	Clay, silty, hard, white at top, green at base
41-42	Sand, very fine, dark gray, cemented, hard
42-49	Clay, silty, white to gray
49-55	Sand, very fine, dark blue-gray

Hole 22070

Date: 7-21-76 Type Rig: Rotary
Casing: 4 in. plastic to 11.5 ft.
Screen: 4 in. slotted (0.16 in.) plastic 11.5 to 16.5 ft.
Remarks: Drilled with clear water, sand pack 10 to 28 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-2	Soil
2-5	Sand, fine
5-11	Clay, sandy
11-16	Sand, fine, with coal fragments at base
16-30	Clay, gray, sandy at top with coal stringers, sandy at base, Sentinel Butte Fm.

Hole 22080

Date: 7-20-76 Type Rig: Rotary
Casing: 4 in. plastic to 68 ft.
Screen: 4 in. slotted (.016 in.) plastic 68 to 74 ft.
Remarks: Drilled with clear water, sand pack 65 to 75 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-2	Soil
2-14	Sand, fine, with clay stringers
14-16	Sand, medium to coarse, gravel
16-19	Clay, coal lense at base, Sentinel Butte Fm.
20-27	Clay, sandy, gray-white
27-31	Sand, very fine, cemented, hard
31-49	Sand, clayey
49-75	Sand, very fine, cemented lenses alternate with soft layers

Hole 22090

Date: 7-21-77 Type Rig: Rotary
Casing: 4 in. plastic to 13 ft.
Screen: 4 in. slotted (.016 in.) plastic 13 to 18 ft.
Remarks: Drilled with clear water, sand pack 12 to 29 ft., hole sealed with granular bentonite, used as observation well in pump test.

Log: Depth in Feet

0-2	Soil
2-18	Sand, fine
18-20	Sand, medium to coarse, with gravel
20-30	Clay, silty and sandy, gray, Sentinel Butte Fm.

Hole 22100

Date: 7-21-76 Type Rig: Rotary
Casing: 4 in. plastic to 10 ft.
Screen: 4 in. slotted (.016 in.) plastic 10 to 14 ft.
Remarks: Drilled with clear water, sand pack 9 to 18 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-3	Soil
3-11	Sand, fine
11-14	Sand, medium to coarse, gravel, red-brown to yellow color
14-20	Clay, gray, Sentinel Butte Fm.

Hole 22110

Date: 7-21-76 Type Rig: Rotary
Casing: 4 in. plastic to 19 ft.
Screen: 4 in. slotted (.016 in.) plastic 19 to 24 ft.
Remarks: Drilled with clear water, sand pack 18 to 26 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-3	Soil
3-12	Sand, fine, brown
12-13	Sand, gravel
13-23	Sand, gray
23-24	Sand, gravel
24-26	Clay, gray, Sentinel Butte Fm.

Hole 22120

Date: 7-21-76 Type Rig: Rotary
Casing: 4 in. plastic to 32 ft.
Screen: 4 in. slotted (.016 in.) plastic 32 to 37 ft.
Remarks: Drilled with clear water, sand pack 27 to 40 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-11	Dike fill material
11-35	Sand, fine, gray-brown, with coal fragments
35-37	Sand, medium to coarse, gravel
37-40	Clay, gray, Sentinel Butte Fm.

Hole 22130

Date: 7-21-76 Type Rig: Rotary
Casing: 4 in. plastic to 49 ft.
Screen: 4 in. slotted (.016 in.) plastic 49 to 55 ft.
Remarks: Drilled with clear water, sand pack 46 to 56 ft., hole sealed with granular bentonite.

Log: Depth in Feet

0-11	Dike fill material
11-35	Sand, fine, clay streaks at top, gray-brown
35-37	Sand, gravel
37-51	Clay, sandy, silty, Sentinel Butte Fm.
51-56	Sand, very very fine, blue-gray

Hole 22140

Date: 7-24-76 Type Rig: Rotary

Casing: 6 in. plastic to 15 ft.

Screen: 6 in. slotted (.016 in.) plastic 15 to 20 ft.

Remarks: Drilled with clear water, sand pack 10 to 23 ft., hole sealed with granular bentonite, screen air developed for 15 min., automatic water-level recorder well, and used as observation well in pump test.

Log: Depth in Feet

0-5	Soil
5-15	Sand, fine, with gravel lense at 8 ft.
15-20	Sand, medium to coarse, with gravel
20-23	Clay, gray, Sentinel Butte Fm.

Hole 22170

Date: 7-21-76 Type Rig: Tripod rotary

Casing: 2 in. plastic to 7 ft.

Screen: 2 in. saw-cut plastic 7 to 11 ft.

Remarks: Drilled with clear water, sand pack 6 to 12 ft., hole sealed with bentonite, split spoon sample taken 10.5 to 12 ft.

Log: Depth in Feet

0-0.5	Soil
0.5-10.5	Sand, silty
10.5-12	Sand, medium to coarse, gravel and coal
12	Clay, gray, Sentinel Butte Fm.

Hole 22180

Date: 7-23-76 Type Rig: Portable auger

Casing: 2 in. plastic to 18 ft.

Screen: 2 in. slotted (.020 in.) plastic 18 to 23 ft.

Remarks: Hole augered and screen jetted into place, used as observation well in pump test, hole sealed with granular bentonite.

Log: Depth in Feet

No log for this hole

Hole 22190

Date: 7-20-76 Type Rig: Portable auger
Casing: 2 in. plastic 16.5 ft.
Screen: 2 in. slotted (.020 in.) plastic 16.5 to 18.5 ft.
Remarks: Hole augered and then screen jetted into position, hole sealed with bentonite.

Log: Depth in Feet

0-4	Soil
4-17	Sand, fine, silty
17-18	Sand, medium to coarse, gravel and coal
18-18.5	Clay, gray, Sentinel Butte Fm.

Hole 22200

Date: 7- -76 Type Rig: Sharpshooter
Casing: 2 in. plastic to 1.5 ft.
Screen: 2 in. slotted (.020 in.)
Remarks: Hole dug with sharpshooter, screen attached to casing at right angles in shape of "tee," hole located at site of a seep in the alluvial bank.

Log: Depth in Feet

0-1	Soil
1-1.5	Gravel and sand
1.5	Clay

Hole 22210

Date: 7-19-76 Type Rig: Tripod rotary
Casing: 2 in. plastic to 13 ft.
Screen: 2 in. slotted (.020 in.) plastic 11.5 to 15.5 ft.
Remarks: Drilled with clear water to 15 ft., took split spoon sample to 17 ft., sealed hole with granular bentonite.

Log: Depth in Feet

0-5	Soil
5-15	Sand, fine, silty
15-17	Sand, medium to coarse, gravel

Hole 22220

Date: 7-19-76 Type Rig: Portable auger
Casing: 2 in. plastic to 10.5 ft.
Screen: 2 in. slotted (.020 in.) plastic 13.5 to 18.5 ft.
Remarks: Hole augered to 20 ft., jetted screen to 18.5 ft., screened, hole sealed with granular bentonite.

Log: Depth in Feet

0-5	Soil
5-15	Sand, fine, silty
15-17	Sand, medium to coarse, gravel
17-20	Clay, sandy, Sentinel Butte Fm.

APPENDIX B

DATA TABLES FOR ALL WATER, SOIL, AND PLANT SAMPLES

LEGEND

Sample code numbers are explained in Section 7, "Results and Discussion."

99.9 means too numerous to count.

Negative sign (-) means less than.

Values in μg/g x 20^{-4} = percentage.

TABLE B-1. WATER QUALITY DATA

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	TEMP DEG C	DISSOLVED OXYGEN MG/L	PH	CONDUC-TIVITY UMHOS/CM	TOTAL ALKALINITY MG/L CACO3	DISSOLVED SOLIDS MG/L	SUSPENDED SOLIDS MG/L	TOTAL SOLIDS MG/L	VOLATILE SUSPENDED SOLIDS MG/L	BOD MG/L	COD MG/L	CL MG/L
216002	11/10/76				8.1	1522.	136.	1022.					59.	23.
216003	3/31/77			4.2	9.5	1533.	160.	1081.				-1.	44.	15.
214601	7/29/76			8.3	8.8	1680.	348.	1119.	23.	1142.		7.	60.	20.
210801	7/29/76	4.0	10.0	6.8	7.9	2016.	516.	1394.				1.	28.	25.
210802	11/11/76	4.0		6.0	7.8	1860.	416.	1329.				-1.	28.	16.
210701	7/29/76	6.4	10.0	1.0	8.3	2080.	456.	1038.				1.	20.	17.
210702	11/11/76	6.4		4.3	8.2	2041.	454.	1375.				-1.	8.	15.
210703	3/31/77	6.4		2.7	8.1	2650.	472.	1391.				2.	28.	15
210704	6/16/77	6.4	10.0	2.2	8.2	1984.	466.	1389.				-1.	16.	73.
210601	7/29/76	11.9	10.0	0.7	8.5	1820.	472.	1182.				-1.	10.	20.
210602	11/11/76	11.9		1.7	8.4	1857.	528.	1248.				-1.	4.	12.
210603	3/31/77	11.9		2.5	8.5	1656.	496.	1169.				2.	32.	19.
210604	6/16/77	11.9	10.0	2.0	8.6	1800.	518.	1258.				-1.	15.	38.
210301	7/29/76	2.4		6.1	7.6	1577.	384.	998.				1.	20.	25.
210302	11/11/76	2.4		1.0	7.5	1845.	404.	1325.				-1.	20.	19.
210303	4/ 3/77	2.4	13.5	2.0	7.8	1644.	412.	1319.				1.	27.	37.
210304	6/16/77	2.4	10.5	6.6	7.6	1652.	385.	1208.				-1.	16.	68.
210201	7/29/76	2.8	10.0	3.0	8.1	1746.	660.	1147.				1.	24.	17.
210201	7/29/76	8.8	10.0	3.0	8.1	1746.	660.	1147.				1.	24.	17.
210202	11/11/76	8.8		3.1	8.1	1740.	502.	1093.				-1.	24.	12.
210203	4/ 3/77	8.8	13.0	6.5	8.1	1586.	604.	1150.				1.	18.	17.
210101	7/29/76	16.5		3.4	8.1	2400.	880.	1633.				-1.	16.	8.
210102	11/10/76	16.5		2.4	8.2	2079.	636.	1430.				1.	16.	6.
210103	4/ 3/77	16.5	10.5	3.5	8.6	2139.	792.	1601.				2.	15.	8.
210501	7/29/76	4.6		5.9	7.3	1512.	288.	1101.				-1.	20.	20.

TABLE B-1. Continued

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	TEMP DEG C	DISSOLVED OXYGEN MG/L	PH	CONDUC- TIVITY UMHOS/CM	TOTAL ALKALINITY MG/L CACO3	DISSOLVED SOLIDS MG/L	SUSPENDED SOLIDS MG/L	TOTAL SOLIDS MG/L	VOLATILE SUSPENDED SOLIDS MG/L	BOD MG/L	COD MG/L	CL MG/L
210502	11/11/76	4.6		3.7	7.5	2340.	328.	1281.				-1.	14.	14.
210503	4/ 3/77	4.6	10.0	2.6	7.7	1596.	344.	1277.				1.	20.	23.
210504	6/16/77	4.6	10.5	3.6	7.5	1637.	345.	1206.				-1.	15.	49.
210401	7/29/76	10.4		2.4	8.0		564.	951.				1.	8.	14.
210402	11/11/76	10.4		1.2	8.1	1600.	380.	1011.				-1.	24.	18.
210901	7/29/76	5.2		1.8	7.4	2057.	404.	1512.				-1.	26.	25.
210902	11/11/76	5.2		1.2	7.2	1890.	424.	1374.				-1.	8.	21.
211501	7/28/76	6.2		2.8	8.3	2916.	600.	2326.				1.	20.	7.
211502	11/11/76	6.2		0.8	8.3	3690.	580.	2504.				2.	36.	3.
224601	7/29/76			14.6	9.5	2205.	404.	1578.	247.	1825.		53.	405.	107.
224602	11/ 9/76			10.2	8.1	2448.	356.	1726.	46.	1772.	4.	24.	227.	103.
224603	4/ 1/77			-0.1	7.6	585.	112.	392.	19.	411.	10.	28.	105.	28.
224604	6/15/77		25.5	14.3	9.6	1617.	188.	1184.	172.	1356.	135.	74.	320.	95.
224605	6/17/77			7.0	0.0	1581.	226.	1132.	66.	1198.	46.	29.	181.	
220201	7/28/76	5.5		1.2	7.0	2340.	484.	2414.				1.	44.	85.
220202	11/ 9/76	5.5		3.5	7.5	3780.	540.	3237.				1.	66.	86.
220203	4/ 2/77	5.5	10.0	1.7	7.1	3050.	554.	2796.				1.	48.	91.
220204	6/15/77	5.5	8.5	0.1	7.4	3121.	610.	2730.				-1.	40.	138.
220101	7/28/76	11.3		5.5	7.9	3723.	592.	2578.				3	48.	89.
220102	11/11/76	11.3		1.7	7.3	3720.	548.	3151.				-1.	44.	89.
220103	4/ 2/77	11.3	12.0	2.6	7.3	3150.	560.	2883.				10.	78.	94.
220301	7/28/76	13.7		6.6	8.0	2808.	956.	2199.				-1.	40.	28.
220302	11/11/76	13.7		2.8	7.3	3075.	584.	2313.				-1.	44.	67.
220303	4/ 2/77	13.7	5.0	1.0	7.6	2600.	540.	2251.				1.	54.	94.
220304	6/17/77	13.7	10.0	1.5	7.6	3168.	648.	2753.				8.	66.	108.

TABLE B-1. Continued

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	TEMP DEG C	DISSOLVED OXYGEN MG/L	PH	CONDUC-TIVITY UMHOS/CM	TOTAL ALKALINITY MG/L CACO3	DISSOLVED SOLIDS MG/L	SUSPENDED SOLIDS MG/L	TOTAL SOLIDS MG/L	VOLATILE SUSPENDED SOLIDS MG/L	BOD MG/L	COD MG/L	CL MG/L
221101	7/28/76	5.8	11.0	1.3	6.1	4825.	516.	4533.				1.	52.	113.
221102	11/ 9/76	5.8		2.4	7.5	4197.	576.	3924.				-1.	51.	116.
221103	3/31/77	5.8	10.0	1.9	7.3	4283.	608.	4716.				3.	70.	114.
221104	6/15/77	5.8	8.0	0.5	7.6	4500.	589.	4698.				-1.	41.	133.
220501	7/28/76	4.0		3.5	7.2	6000.	604.	6143.				1.	52.	113.
220502	11/ 9/76	4.0		1.0	7.6	5430.	640.	5845.				-1.	62.	92.
220503	3/31/77	4.0		2.2	7.5	5900.	608.	6397.				1.	72.	103.
220504	6/16/77	4.0	19.0	1.3	8.2	5800.	629.	6573.				1.	63.	136.
220401	7/28/76	5.8		6.2	7.2		556.	6491.				-1.	83.	106.
220402	11/10/76	5.8		1.6	7.2	5350.	624.	5695.				1.	57.	94
220403	3/31/77	5.8	11.5	1.3	7.5	4826.	644.	5408.				2.	66.	96.
221201	7/29/76	9.8		0.5	7.1	2200.	556.	1528.				1.	48.	95.
221202	11/10/76	9.8		0.3	7.3	2386.	618.	1680.				1.	36.	97.
221203	4/ 2/77	9.8		-0.1	7.2	2168.	622.	1713.				1.	45.	100.
221204	6/16/77	9.8	12.0	2.4	7.4	2218.	645.	1704.				1.	45.	112.
221301	7/29/76	14.9	10.0	6.3	8.3	3332.	716.	2430.				-1.	32.	20.
221302	11/10/76	14.9		4.4	7.9	3174.	744.	2355.				1.	39.	6.
221303	4/ 2/77	14.9	11.0	-0.1	7.4	2268.	664.	1769.				3.	75.	102.
221701	7/28/76	2.1		1.5	7.1	2294.	788.	1594.				1.	28.	95.
221702	11/ 9/76	2.1		1.2	7.4	2475.	600.	1730.				1.	66.	92.
221703	4/ 2/77	2.1	5.0	3.1	7.2	2100.	596.	1721.				1.	59.	99.
221704	6/15/77	2.1	77.7	5.9	7.4	2235.	648.	1699.				-1.	49.	115.
221001	7/28/76	3.0	11.0	2.5	7.1		536.	5792.				1.	79.	95.
221002	11/ 9/76	3.0		1.0	7.5	5443.	604.	5432.				1.	82.	92.
221003	4/ 2/77	3.0	7.5	2.4	7.2	4554.	584.	5393.				1.	75.	104.

TABLE B-1. Continued

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	TEMP DEG C	DISSOLVED OXYGEN MG/L	PH	CONDUC-TIVITY UMHOS/CM	TOTAL ALKALINITY MG/L CACO3	DISSOLVED SOLIDS MG/L	SUSPENDED SOLIDS MG/L	TOTAL SOLIDS MG/L	VOLATILE SUSPENDED SOLIDS MG/L	BOD MG/L	COD MG/L	CL MG/L
221004	6/15/77	3.0	8.5	4.8	7.6	4779.	727.	4996.				-1.	55.	187.
221901	7/28/76	4.9	10.0	1.0	6.4	4620.	392.	5392.				1.	107.	92.
221902	11/10/76	4.9		1.3	7.3	5108.	412.	5698.				-1.	109.	97.
221903	4/ 1/77	4.9	12.0	1.2	6.5	4575.	404.	5622.				1.	103.	93.
221904	6/17/77	4.9	8.0	0.5	6.7	4738.	437.	5659.				-1.	93.	105.
220701	7/28/76	3.4	15.0	4.0	7.2	6200.	636.	7402.				2.	97.	92.
220702	11/10/76	3.4		2.7	7.2	6044.	564.	6843.				1.	94.	97.
220703	4/ 1/77	3.4	14.5	6.8	7.7	4543.	672.	5511.				-1.	80.	60.
220601	7/29/76	14.9		1.1	8.1	3952.	768.	2904.				1.	36.	7.
220602	11/10/76	14.9		1.5	8.0	3894.	806.	2706.				2.	31.	-1.
220603	4/ 1/77	14.9	9.0	2.5	8.0	3660.	696.	2905.				-1.	25.	8.
220604	6/17/77	14.9	9.0	3.6	8.2	3705.	802.	2959.				-1.	10.	35.
220801	7/29/76	20.7		1.2	8.2	4158.	836.	3161.				4.	20.	8.
220802	11/10/76	20.7		5.4	8.2	4084.	812.	3063.				1.	47.	-1.
220803	4/ 1/77	20.7	9.0	1.9	8.0	3748.	804.	3115.				-1.	26.	8.
220804	6/17/77	20.7	7.5	3.5	8.2	3933.	827.	2907.				-1.	11.	36.
220901	7/28/76	4.0		4.1	7.0	1998.	476.	1785.				1.	28.	92.
220902	11/ 9/76	4.0		2.3	7.4	2029.	562.	1454.				1.	45.	80.
220904	6/15/77	4.0	7.5	3.0	7.4	2346.	573.	1865.				-1.	34.	122.
222001	7/28/76	0.9	10.0	5.0	7.2		604.	4784.				-1.	52.	92.
222002	11/ 9/76	0.9		3.6	7.5	4384.	568.	4629.				-1.	113.	96.
222003	4/ 1/77	0.9	12.0	4.4	7.1	3840.	504.	4963.				-1.	69.	90.
222004	6/16/77	0.9	11.0	5.4	7.3	4563.	524.	5281.				-1.	54.	83.
224101	7/30/76				8.2	3366.	596.						97.	144.
224104	6/15/77													

TABLE B-1. Continued

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	TEMP DEG C	DISSOLVED OXYGEN MG/L	PH	CONDUC-TIVITY UMHOS/CM	TOTAL ALKALINITY MG/L CACO3	DISSOLVED SOLIDS MG/L	SUSPENDED SOLIDS MG/L	TOTAL SOLIDS MG/L	VOLATILE SUSPENDED SOLIDS MG/L	BOD MG/L	COD MG/L	CL MG/L
224201	7/30/76				8.3		588.						166.	163.
224301	7/30/76				7.5		676.	3541.					69.	95.
224304	6/15/77												106.	

TABLE B-1. Continued

SAMPLE NUMBER	SULFIDE-SULFUR MG/L-S	TOTAL COLIFORM #/100ML	FECAL COLIFORM #/100ML	TOTAL ORGANIC CARBON MG/L-C	DISSOLVED ORGANIC CARBON MG/L-C	TOTAL ORGANIC NITROGEN MG/L-N	SOLUBLE ORGANIC NITROGEN MG/L-N	NH4 MG/L-N	NO3 MG/L-N	TOTAL PHOSPHORUS MG/L-P	SOLUBLE PHOSPHORUS MG/L-P	SOLUBLE ORTHO-PHOSPHATE MG/L-P
216002		0.	0.				0.8	-0.1	1.0			
216003	-0.1	1.	0.		11.7		0.3	0.2	0.4		0.36	0.18
214601		533.	33.	22.6	18.4	1.3	0.1	0.1	4.0	0.05	0.03	-0.01
210801		0.	0.		11.4		0.4	0.4	0.3		-0.01	-0.01
210802		4.	0.				0.4	0.2	0.2		0.13	-0.01
210701		0.	0.		11.2		0.2	0.3	0.1		0.02	0.01
210702		134.	0.				0.7	0.3	0.2		0.04	0.04
210703	-0.1	100.	0.				1.5	-0.1	-0.1		0.08	0.06
210704		0.	0.				0.7	0.3	-0.1		0.19	0.15
210601		0.	0.		7.0		0.2	0.3	-0.1		0.02	-0.01
210602		0.	0.				0.6	0.2	0.2		0.07	0.07
210603	-0.1	99.9	0				0.6	0.1	-0.1		0.13	0.10
210604		0.	0.		15.9		0.5	0.4	-0.1		0.12	0.09
210301		0.	0.		12.8		0.5	0.2	1.3		-0.01	-0.01
210302		4.	0.				0.9	0.4	1.2		0.13	0.01
210303	-0.1	0.	0.		8.5		0.2	0.3	0.4		0.03	0.02
210304		0.	0.		15.7		0.8	0.2	0.6		0.07	0.06
210201		0.	0.		10.6		0.5	0.3	-0.1		0.02	0.01
210202		1367.	0.				0.4	0.4	0.1		0.19	0.09
210203	-0.1	0.	0.		19.4		0.5	0.3	-0.1		0.09	0.08
210101		0.	0.		4.7		1.9	0.5	-0.1		-0.01	-0.01
210102		88.	0.				0.7	0.5	0.2		0.24	0.22
210103	-0.1	0.	0.				0.3	0.2	-0.1		0.14	0.11
210501		0.	0.		5.7		0.4	0.3	1.9		-0.01	-0.01
210502		0.	0.				1.0	0.2	1.1		0.03	0.02

TABLE B-1. Continued

SAMPLE NUMBER	SULFIDE-SULFUR MG/L-S	TOTAL COLIFORM #/100ML	FECAL COLIFORM #/100ML	TOTAL ORGANIC CARBON MG/L-C	DISSOLVED ORGANIC CARBON MG/L-C	TOTAL ORGANIC NITROGEN MG/L-N	SOLUBLE ORGANIC NITROGEN MG/L-N	NH4 MG/L-N	NO3 MG/L-N	TOTAL PHOSPHORUS MG/L-P	SOLUBLE PHOSPHORUS MG/L-P	SOLUBLE ORTHO-PHOSPHATE MG/L-P
210503	-0.1	0.	0.		15.5		0.3	0.1	0.4		0.01	0.01
210504		0.	0.		6.8		0.6	0.3	0.7		0.04	0.03
210401		0.	0.				0.4	0.3	0.4		0.02	0.02
210402		467.	0.				0.9	0.2	0.3		0.14	0.12
210901		0.	0.		10.7		0.2	0.2	0.9		-0.01	-0.01
210902		6.	0.				2.8	0.2	0.5		-0.01	-0.01
211501		0.	0.		5.0		-0.1	0.3	0.9		0.03	0.02
211502		1225.	0.				1.9	0.5	0.1		0.13	0.12
224601		767.	0.	95.6	3.5	0.9	-0.1	1.3	3.6	3.00	0.50	0.32
224602		99.9	7100.	15.3	1.6			13.9	2.1	10.20	8.50	7.50
224603	0.2	99.9	0.	21.5	17.4	-0.1	-0.1	5.6	-0.1	4.60	4.30	1.10
224604		99.9	1950.	66.7	36.7	9.4	3.2	8.2	1.0	10.00	5.20	5.00
224605		99.9	99.	67.3	32.0		11.4	5.7	0.8	6.80	5.60	5.20
220201		0.	0.		15.0		0.8	-0.1	0.8		0.05	0.03
220202		6.	0.				2.7	0.5	1.2		0.04	0.02
220203	-0.1	0.	0.		19.4		0.8	0.9	-0.1		0.01	0.01
220204		0.	0.		40.7		2.6	0.6	-0.1		0.02	0.02
220101		367.	0.		16.6		0.9	0.3	0.9		0.04	-0.01
220102		0.	C				2.3	0.6	0.7		0.13	0.02
220103	-0.1	0.	0.		20.7		2.0	1.4	-0.1		0.01	0.01
220301		0.	0.		10.8		-0.1	0.8	1.3		0.02	-0.01
220302		4.	0.				0.6	0.4	0.4		0.17	0.01
220303	-0.1	0.	0.		28.5		0.4	0.9	-0.1		-0.01	-0.01
220304		0.	0.		41.2		2.2	0.6	0.0		0.05	0.02
221101		0.	0.		20.5		1.0	1	2.9		0.04	0.03

TABLE B-1. Continued

SAMPLE NUMBER	SULFIDE-SULFUR MG/L-S	TOTAL COLIFORM #/100ML	FECAL COLIFORM #/100ML	TOTAL ORGANIC CARBON MG/L-C	DISSOLVED ORGANIC CARBON MG/L-C	TOTAL ORGANIC NITROGEN MG/L-N	SOLUBLE ORGANIC NITROGEN MG/L-N	NH4 MG/L-N	NO3 MG/L-N	TOTAL PHOSPHORUS MG/L-P	SOLUBLE PHOSPHORUS MG/L-P	SOLUBLE ORTHO-PHOSPHATE MG/L-P
221102		0.	0.				1.7	0.4	3.7		-0.01	-0.01
221103	-0.1	2.	0.		18.1		0.5	-0.1	-0.1		0.07	0.06
221104		0.	0.		39.8		1.3	0.5	0.1		0.03	0.02
220501		0.	0.		23.9		1.1	-0.1	2.1		0.04	0.02
220502		0.	0.				2.7	0.3	2.9		0.12	0.02
220503	-0.1	0.	0.		34.6		0.4	-0.1	0.3		0.09	0.08
220504		0.	0.		29.2		1.1	0.4	0.2		0.06	0.02
220401		0.	0.		23.9		0.3	-0.1	0.4		0.05	0.03
220402		20.	0.				0.9	0.4	0.8		0.02	0.02
220403	-0.1	85.	0.		49.1		0.9	-0.1	0.3		0.05	0.03
221201		0.	0.		18.8		0.3	0.6	2.5		-0.01	-0.01
221202		0.	0.				2.6	0.6	1.5		0.02	0.02
221203	-0.1	0.	0.		28.2		3.3	1.6	-0.1		0.02	0.02
221204		0.	0.		47.8		0.7	1.0	-0.1		0.04	0.03
221301		0.	0.		13.2		0.2	0.4	2.8		0.04	-0.01
221302		0.	0.				1.4	1.2	0.9		0.16	0.09
221303	-0.1	0.	0.		21.2		2.8	2.8	0.1		0.01	0.01
221701		0.	0.		22.9		0.6	0.9	1.8		-0.01	-0.01
221702		0.	0.				1.2	0.9	2.8		0.02	0.02
221703	-0.1	0.	0.		24.1		1.9	1.2	-0.1		0.01	-0.01
221704		0.	0.		25.9		2.8	1.2	-0.1		0.02	0.02
221001		0.	0.		25.8		0.3	0.2	2.5		0.05	0.03
221002		0.	0.				0.5	0.3	2.8		0.07	0.04
221003	-0.1	0.	0.		20.2		1.1	1.2	1.3		0.02	-0.01
221004		1.	0.		45.4		2.1	0.2	0.5		0.07	0.05

TABLE B-1. Continued

SAMPLE NUMBER	SULFIDE-SULFUR MG/L-S	TOTAL COLIFORM #/100ML	FECAL COLIFORM #/100ML	TOTAL ORGANIC CARBON MG/L-C	DISSOLVED ORGANIC CARBON MG/L-C	TOTAL ORGANIC NITROGEN MG/L-N	SOLUBLE ORGANIC NITROGEN MG/L-N	NH4 MG/L-N	NO3 MG/L-N	TOTAL PHOSPHORUS MG/L-P	SOLUBLE PHOSPHORUS MG/L-P	SOLUBLE ORTHO-PHOSPHATE MG/L-P
221901		0.	0.		31.6		0.8	0.1	1.5		0.04	0.02
221902		256	0.		81.8		3.4	0.3	2.0		0.05	-0.01
221903	-0.1	1.	0.		27.1		0.3	0.2	0.8		0.07	0.04
221904		0.	0.		44.3		1.6	0.8	0.9		0.06	0.02
220701		100.	0.		34.1		1.2	0.8	1.9		-0.01	-0.01
220702		2.	0.		85.9		0.8	0.3	2.1		0.22	0.02
220703	-0.1	0.	0.		23.8		0.6	0.2	1.0		0.04	0.04
220601		0.	0.		6.3		0.9	0.4	4.8		0.03	0.02
220602		0.	0.				0.9	0.3	0.3		0.24	0.12
220603	-0.1	283.	0.		17.2		0.3	0.4	-0.1		0.11	0.10
220604		0.	0.				2.1	0.5	-0.1		0.13	0.12
220801		667.	0.		8.4		1.0	0.6	4.8		0.02	0.01
220802		933.	0.				1.0	0.6	0.3		0.32	0.07
220803	-0.1	94.	0.		15.8		0.6	0.3	-0.1		0.12	0.11
220804		75.	0.				1.3	0.5	-0.1		0.10	0.09
220901		0	0.		12.8		0.1	0.2	0.8		0.05	0.03
220902		0	0.		22.7		1.1	0.3	5.3		0.02	0.02
220903	-0.1	0.	0.				0.5	0.1	-0.1		0.06	0.05
220904		0.	0.		15.2		2.5	0.3	2.0		0.04	0.02
222001		0.	0.		24.8		0.6	0.3	2.5		-0.01	-0.01
222002		0.	0.		80.2		3.8	0.2	6.1		0.02	0.02
222003	-0.1	5.	0.		38.9		0.9	0.1	20.0		0.05	0.05
222004		0.	0.		38.0		1.8	0.3	1.6		0.05	0.02
224101		0.	0.		63.2		-0.1	0.8	75.0	0.20		
224104		0	0				15.7	0.7	0.2			

TABLE B-1. Continued

SAMPLE NUMBER	SULFIDE-SULFUR MG/L-S	TOTAL COLIFORM #/100ML	FECAL COLIFORM #/100ML	TOTAL ORGANIC CARBON MG/L-C	DISSOLVED ORGANIC CARBON MG/L-C	TOTAL ORGANIC NITROGEN MG/L-N	SOLUBLE ORGANIC NITROGEN MG/L-N	NH4 MG/L-N	NO3 MG/L-N	TOTAL PHOSPHORUS MG/L-P	SOLUBLE PHOSPHORUS MG/L-P	SOLUBLE ORTHO-PHOSPHATE MG/L-P
224201		0.	0.		40.4		0.5	0.8	73.0	0.09		
224301		0.	0.		33.4		-0.1	0.8	76.0	0.02		
224304		0.	0		56.7		6.4	0.3	0.8	1.50		

TABLE B-1. Continued

SAMPLE NUMBER	SO4 MG/L-SO4	AL MG/L-AL	AS UG/L-AS	B UG/L-B	CD UG/L-CD	CA MG/L-CA	CO UG/L-CO	CR UG/L-CR	CU UG/L-CU	FE MG/L-FE	PB UG/L-PB	MG MG/L-MG	MN MG/L-MN
216002	580.	-0.3	12.	527	-20	50.	-50.	-50.	-20.	-0.1	-100.	11.0	-0.05
216003	606.	-1.0	-5.	346	-20.	39.	-50.	-50.	-20.	-0.5	-200.	7.1	-0.10
214601		0.2	-10.	250	-10	55.	-20.	-20.	-10.	-0.2	-100.	30.0	0.23
210801		3.4	-10.	170.	44.	91.	-20	-20	10.	2.6	-100.	22.0	0.11
210802	467.	-0.3	7.	858.	-20.	109.	-50.	-50.	-20.	1.0	-100.	33.0	-0.05
210701		0.7		130.	-10.	27.	-20.	-20.	15.	-0.2	-100.	3.0	-0.05
210702	549.	-0.3	-5.	950.	-20.	12.	-50.	-50.	-20.	0.1	-100.	12.0	-0.05
210703	608	-1.0	-5	760.	-20.	9.	-50.	-50.	-20.	-0.5	-200.	4.3	-0.10
210704	550.	-0.3	8.	664		29.		-100.	-50.				-0.05
210601	353.	3.8	-10.	120	-10.	27.	-20.	-20.	10.	3.5	-100.	2.5	0.13
210602	376.	16.9	-5	1032.	-20.	15.	-50.	-50.	-20.	19.9	-100.	15.0	0.48
210603	394.	-1.0	-5.	920.	-20.	4.	-50.	-50.	-20.	-0.5	-200.	1.5	-0.10
210604	604	-0.3	9.	600.				-100.	-50.	-0.2		1.0	-0.05
210301	594.	-0.3	-10.	120.	-10.	80.	-20.	-20.	10.	-0.2	-100.	20.0	0.05
210302	501.	0.4	-5.	588.	-20.	107.	-50.	-50	-20.	1.3	-100.	38.0	0.09
210303	626.	-1.0	-5.	375.	-20.	110.	-50.	-50	-20.	1.0	-200.	35.0	-0.10
210304	613.	-0.3	12.	363.		110.		-100	-50.	-0.2		28.0	-0.05
210201		16.8	11.	180.	-10.	25.	-20	-20	40.	10.8	-100.	9.5	0.17
210202	315.	1.0	-5.	1082.	-20.	5.	-50.	-50.	-20	1.2	-100.	2.5	0.05
210203	398	-1.0	-5.	603.	-20.	13.	-50.	-50.	-20.	-0.5	-200.	8.2	-0.10
210101		3.4		250.	-10	23.	-20	-20.	10.	3.8	-100.	10.0	0.12
210102	393.	-0.3	-5.	1192.	-20.	89.	-50.	-50.	-20.	0.3	-100.	8.6	0.28
210103	519.	-1.0	-5.	897	-20	13.	-50	-50.	-20	2.4	-200.	11.0	-0.10
210501		0.2	-10	260.	-10.	112.	-20	-20	-10.	-0.2	-100.	24.0	0.16
210502	554	-0.3	14.	684	-20	94.	-50	-50	-20	1.0	-100.	35.0	0.05

TABLE B-1. Continued

SAMPLE NUMBER	SO4 MG/L-SO4	AL MG/L-AL	AS UG/L-AS	B UG/L-B	CD UG/L-CD	CA MG/L-CA	CO UG/L-CO	CR UG/L-CR	CU UG/L-CU	FE MG/L-FE	PB UG/L-PB	MG MG/L-MG	MN MG/L-MN
210503	613.	-1.0	-5.	292.	-20.	1070.	-50,	-50.	-20.	-0.5	-200.	33.0	1.00
210504	631.		11.	358.		110.		-100.	-50.	0.2		27.0	-0.05
210401		2.1	-10.	160.	-10.	38.	-20.	-20.	11.	2.9	-100.	2.3	0.06
210402	310.	0.7	-5.	1310.	-20.		-50.	-50.	-20.	1.2	-100.	12.0	0.11
210901		0.7		160.	-10.	179.	-20.	-20.	-10.	0.7	-100.	37.0	0.54
210902	574.	0.9	-5.	1158.	-20.	115.	-50.	-50.	-20.	3.5	-100.	44.0	0.65
211501		3.1		210.	-10.	8.	-20.	-20.	10.	2.8	-100.	6.4	0.08
211502	1318.	-0.3		1118.	-20.	6.	-50.	-50.	-20.	0.8	-100.	15.0	0.07
224601	333.	0.7		160.	-10.	61.	-20.	-20.	20.	1.1	-100	20.0	0.06
224602	853.	-0.3	-5.	2724.	-20.	123.	-50.	-50.	-20.	0.9	-100	22.0	0.09
224603	116.	-1.0	-5.	185.	-20.	8.	-50.	-50.	-20.	0.4	-200.	2.9	-0.10
224604	135.	-0.3	10.	617.		43.		-100.	-50.	0.2		15.0	-0.05
224605		0.8	11.			38.		-100.	-50.	0.9		14.0	-0.05
220201		-0.3	-10.	140.	-10.	149.	-20.	-20.	10.	-0.2	-100.	44.0	3.20
220202	1719.	-0.3	14.		-20.	322.	-50.	-50.	-20.	1.7	-100.		4.60
220203	1442.	-1.0	-5.	536.	-20.	240.	-50.	-50.	-20.	2.8	-200.	98.0	3.80
220204	1230.	-0.3	10.	415.		288.		-100.	-50.	2.3		87.0	3.40
220101	1176.	4.0	18.	130.	-10.	117.	-20.	-20.	40.	5.7	-100.	48.0	0.74
220102	1427.	1.3	-5.	798.	-20.	318.	-50.	-50.	188.	3.2	-100.	4.0	3.00
220103	1451.	-1.0	-5.	544.	-20.	260.	-50.	-50.	62.	-0.5	-200.	95.0	3.00
220301	1372.	3.3	17.	120.	-10.	25.	-20.	-20.	50.	3.3	-100.	16.0	0.12
220302	988.	-0.3	-5.	830.	-20.	126.	-50.	-50.	28.	0.1	-100.	44.0	0.13
220303	1055.	-1.0	-5.	569.	-20.	186.	-50.	-50.	-20.	1.8	-200.	70.0	2.60
220304	1167.	-0.3	12.	444.		274.		-100.	203.	-0.2		82.0	2.90
221101		-0.3	23.	180.	-10.	498.	-20.	-20.	10.	4.7	-100.	82.0	0.47

TABLE B-1. Continued

SAMPLE NUMBER	SO4 MG/L-SO4	AL MG/L-AL	AS UG/L-AS	B UG/L-B	CD UG/L-CD	CA MG/L-CA	CO UG/L-CO	CR UG/L-CR	CU UG/L-CU	FE MG/L-FE	PB UG/L-PB	MG MG/L-MG	MN MG/L-MN
221102	2193.	-0.3	-5.	1409.	-20.	400.	-50.	-50.	-20.	1.2	-100.	17.0	0.21
221103	2677.	-1.0	62.	970.	-20.	563.	-50.	-50.	-20.	3.6	-200.	16.0	0.60
221104	2293.	-0.3	20.	828.		399.		-100.	-50.	4.2		80.0	0.51
220501	3136.	-0.3	34.	160.	-10.	764.	-20.	-20.	40.	0.2	-100.	86.0	-0.05
220502	4076.	-0.3	15.	1248.	-20.	849.	-50.	-50.	-20.	2.1	-100.	88.0	0.13
220503	3876.	-1.0	18.	772.	-20.	835.	69.	-50.	34.	6.6	-200.	44.0	0.20
220504	3528.	-0.3	21.	735.		525.		-100.	75.	1.2		89.0	-0.05
220401	3214.	-0.3	35.	260.	-10.	664.	-20.	-20.	40.	-0.2	-100.	82.0	0.33
220402	3918.	-0.3	7.	733.	-20.	650.	-50.	-50.	-20.	0.3	-100.	35.0	0.32
220403	3236.	-1.0	20.	917.	-20.	452.	-50.	-50.	180.	1.8	-200.	94.0	0.70
221201	745.	3.3	12.	120.	-10.	164.	-20.	-20.	10.	14.0	-100.	43.0	3.40
221202		-0.3	-5.	552.	-20.	217.	-50.	-50.	-20.	10.3	-100.	44.0	1.50
221203	692.	-1.0	71.	343.	-20.	176.	-50.	-50.	-20.	11.4	-200.	49.0	1.00
221204	573.	-0.3	11.	285.		182.		-100.	-50.	11.4		42.0	0.94
221301		4.4	16.	200.	-10.	51.	-20.	-20.	30.	3.8	-100.	16.0	0.16
221302	943.	-0.3	12.	542.	-20.	50.	-50.	-50.	142.	0.6	-100.	17.0	0.76
221303	586.	-1.0	68.	474.	-20.	133.	-50.	-50.	-20.	2.0	-200.	36.0	3.60
221701	470.	2.8	12.	120.	-10.	143.	-20.	-20.	10.	3.3	-100.	37.0	5.00
221702	595.	0.5	26.		-20.	172.	-50.	-50.	-20.	3.6	-100.	38.0	4.40
221703	611.	-1.0	16.	499.	-20.	163.	-50.	-50.	-20.	1.6	-200.	49.0	4.20
221704	542.	-0.3	14.	490.		148.		-100.	-50.	1.0		36.0	3.86
221001	2960.	1.5	25.	260.	-10.	293.	-20.	-20.	20.	1.7	-100.	64.0	0.18
221002	3459.	-0.3	7.	7225.	-20.	435.	-50.	-50.	-20.	0.6	-100.	94.0	0.14
221003	3236.	-1.0	8.	1171.	-20.	397.	-50.	-50.	41.	0.5	-200.	24.0	-0.10
221004	2538.	-0.3	21.	1210.		233.		-100.	-50.	0.2		87.0	-0.05

TABLE B-1. Continued

SAMPLE NUMBER	SO4 MG/L-SO4	AL MG/L-AL	AS UG/L-AS	B UG/L-B	CD UG/L-CD	CA MG/L-CA	CO UG/L-CO	CR UG/L-CR	CU UG/L-CU	FE MG/L-FE	PB UG/L-PB	MO MG/L-MO	MN MG/L-MN
221901	2626.	-0.3	-10.	190.	-10.	649.	-20.	-20.	20.	-0.2	-100.	90.0	0.54
221902	4282.	0.4	9.	663.	-20.	588.	-50.	-50.	-20.	0.5		14.0	0.93
221903	3687.	-1.0	10.	661.	50.	741.	-50.	-50.	-20.	1.6	-200.	57.0	1.20
221904	3133.	-0.3	9.	674.		576.		-100.	-50.	0.2		59.0	0.86
220701	4253.	4.4	31.	240.	-10.	626.	-20.	-20.	40.	8.4	-100.		2.10
220702	4610.	-0.3	6.	1027.	-20.	816.	-50.	-50.	-20.	7.8	-100.	86.0	2.60
220703	3326.	-1.0	-5.	908.	-20.	452.	-50.	-50.	76.	3.9	-200.	23.0	1.90
220601	784.	2.9	14.	260.	-10.	27.	-20.	-20.	20.	3.9	-100.		0.13
220602	1402.	-0.3	22.	458.	-20.	46.	-50.	-50.	-20.	1.2	-100.	9.2	0.05
220603	1478.	-1.0	-5.	511.	-20.	39.	-50.	-50.	-20.	0.7	-200.	12.0	-0.10
220604	1348.	-0.3	21.	506.		26.		-100.	-50.	0.3		11.0	-0.05
220801		1.3	22.	200.	-10.	12.	-20.	-20.	10.	2.9	-100.	13.0	0.07
220802	1624.	-0.3	7.	436.	-20.	88.	-50.	-50.	-20.	-0.1	-100.	3.1	-0.05
220803	1541.	-1.0	-5.	514.	-20.	19.	-50.	-50.	-20.	0.5	-200.	13.0	-0.10
220804	1448.	-0.3	19.	507.		26.		-100.	-50.	-0.2		10.0	-0.05
220901	510.	-0.3	-10.	170.	-10.	179.	-20.	-20.	10.	-0.2	-100.	45.0	1.30
220902	519.	-0.3	9.		-20.	100.	-50.	-50.	-20.	0.2	-100.	39.0	1.10
220903	541.	-1.0	10.	637.	-20.	141.	-50.	-50.	-20.	0.9	-200.	30.0	1.80
220904	384.	-0.3	9.	498.		176.		-100.	-50.	0.4		52.0	1.80
222001	3254.	-0.3		100.	-10.	709.	-20.	-20.	10.	-0.2	-100.	95.0	-0.05
222002	3064.	0.5	15.		-20.	620.	-50.	-50.	-20.	3.0	-100.	26.0	0.50
222003	2876.	-1.0	11.	631.	-20.	820.	-50.	-50.	62.	1.2	-200.	58.0	-0.10
222004	1798.	-0.3	13.	498.		417.		-100.	-50.	0.8		9.0	-0.05
224101	1568.	-0.3		140.	-10.	68.	-20.	-20.	20.	0.2	-100.	47.0	0.12
224104						77.							

TABLE B-1. Continued

SAMPLE NUMBER	SO4 MG/L-SO4	AL MG/L-AL	AS UG/L-AS	B UG/L-B	CD UG/L-CD	CA MG/L-CA	CO UG/L-CO	CR UG/L-CR	CU UG/L-CU	FE MG/L-FE	PB UG/L-PB	MG MG/L-MG	MN MG/L-MN
224201	1638.	-0.3		110.	-10.	77.	-20.	-20.	20.	-0.2	-100	89.0	-0.05
224301	1176.	-0.3		140.	-10.	164.	-20.	-20.	40.	-0.2	-100.	68.0	-0.05
224304				545.		77.							

TABLE B-1. Continued

SAMPLE NUMBER	HG UG/L-HG	NI UG/L-NI	K MG/L-K	NA MG/L-NA	ZN UG/L-ZN	SE UG/L-SE	ENDRIN NG/L	LINDANE NG/L	METHOXY-CHLOR NG/L	TOXA-PHENE NG/L	2,4-D NG/L	2,4,5 TP SILVEX NG/L
216002		-50.	9.8	309.	-20.	7.	-0.03	-1.5	-0.01	-0.1	-8.4	86.2
216003	-1.0	97.	8.5	314.	39.	-10.	-0.03	3.8	-0.01	-0.1	10.4	31.4
214601	-1.0	-50.	12.4	309.	-50.	-10.	-0.03	-2.0	-0.01	-0.1	2.7	-0.2
210801	-1.0	-50.	7.3	373.	101.	-10.	-0.03	13.6	-0.01	-0.1	-1.2	-0.2
210802	-1.0	-50.	6.2	387.	187.	9.	-0.03	-1.5	-0.01	-0.1	-8.4	77.6
210701	-1.0	-50.	4.8	466.	58.		-0.03	108.	-0.01	-0.1	-1.2	-0.2
210702	-1.0	-50.	6.7	509.	34.	9.	-0.03	-1.5	-0.01	-0.1	-8.4	96.1
210703	-1.0	-50.	2.5	483.	-20.	-10.	-0.03	26.4	-0.01	-0.1	14.0	21.9
210704		-100.	3.1	415.	57.	-10.	-0.03	36.3	-0.01	-0.1	9.2	6.7
210601	-1.0	-50.	4.7	546.	115.	-10.	-0.03	392.	-0.01	-0.1	1.4	-0.2
210602	-1.0	64.	6.0	474.	414.	7.	-0.03	-1.5	-0.01	-0.1	-8.4	76.5
210603	-1.0	-50.	1.8	454.	-20.	-10.	-0.03	273.	-0.01	-0.1	16.2	23.6
210604		-100.	2.7	415.	-20.	-10.	-0.03	106.	-0.01	-0.1	-1.4	-0.4
210301	-1.0	-50.	8.3	229.	-50.	-10.	-0.03	-2.0	-0.01	-0.1	-1.2	-0.2
210302	-1.0	-50.	8.7	307.	32.	7.	-0.03	-1.5	-0.01	-0.1	-8.4	132.
210303	-1.0	-50.	6.1	297.	39.	-10.	-0.03	-0.4	-0.01	-0.1	15.1	10.3
210304		-100.	6.2	227.	36.	-10.	-0.03	5.3	-0.01	-0.1	12.8	18.0
210201	-1.0	-50.	7.8	406.	-50.	-10.	-0.03	117.	-0.01	-0.1	1.4	-0.2
210202	-1.0	-50.	4.3	339.	41.	7.	-0.03	-1.5	-0.01	-0.1	-8.4	93.6
210203	-1.0	-50.	2.5	382.	139.	10.	-0.03	32.6	-0.01	-0.1	-0.5	70.6
210101		-50.	7.2	581.	-50.		-0.03	73.8	-0.01	-0.1	-1.2	-0.2
210102	-1.0	-50.	5.3	583.	-20.	9.	-0.03	-1.5	-0.01	-0.1	-8.4	58.5
210103	-1.0	-50.	4.3	551.	25.	-10.	-0.03	102.	-0.01	-0.1	52.4	60.3
210501	-1.0	-50.	8.0	257.	74.	-10.	-0.03	91.6	-0.01	-0.1	1.6	-0.2
210502	-1.0	-50.	6.5	283.	-20.	7.	-0.03	-1.5	-0.01	-0.1	-8.4	110.

TABLE B-1. Continued

SAMPLE NUMBER	HG UG/L-HG	NI UG/L-NI	K MG/L-K	NA MG/L-NA	ZN UG/L-ZN	SE UG/L-SE	ENDRIN NG/L	LINDANE NG/L	METHOXY-CHLOR NG/L	TOXA-PHENE NG/L	2,4-D NG/L	2,4,5 TP SILVEX NG/L
210503	-1.0	-50.	5.5	254.	96.	-10.	-0.03	-0.4	-0.01	-0.1	-0.5	8.1
210504		-100.	5.6	213.	32.	-10.	-0.03	5.4	-0.01	-0.1	10.4	8.7
210401		-50.	5.1	404.	-50.	-10.	-0.03	84.0	-0.01	-0.1	2.1	-0.2
210402	-1.0	-50.	3.3	413.	36.	8.	-0.03	-1.5	-0.01	-0.1	-8.4	141.
210901	-1.0	-50.	7.8	293.	-50.		-0.03	41.0	-0.01	-0.1	1.8	-0.2
210902	-1.0	51.	6.7	344.	35.	8.	-0.03	7.5	-0.01	-0.1	-8.4	125.
211501	-1.0	-50.	7.8	851.	-50.		-0.03	62.7	-0.01	-0.1	-1.2	-0.2
211502	-1.0	51.	6.2	925.	82.		-0.03	1.8	-0.01	-0.1	-8.4	272.
224601	-1.0	-50.	41.0	434.	58.		-0.03	82.0	-0.01	-0.1	2.5	-0.2
224602	-1.0	64.	30.8	491.	125.	13.	-0.03	152.	-0.01	-0.1	-8.4	72.8
224603	-1.0	-50.	2.5	56.	17.	-10.	-0.03	1690.	-0.01	-0.1	80.0	354.
224604		-100.	24.0	280.	22.	-10.	-0.03	8.3	-0.01	-0.1	-1.4	17.2
224605		-100.	21.7	267.	29.	-10.	-0.03	54.0	-0.01	-0.1	-1.4	20.2
220201	-1.0	-50.	9.4	357.	-50.	12.	-0.03	3.2	-0.01	-0.1	1.6	-0.2
220202	-1.0	64.	9.2	496.	74.	15.	-0.03	3.3	-0.01	-0.1	-8.4	112.
220203	-1.0	-50.	7.6	551.	96.	-10.	-0.03	1.7	-0.01	-0.1	13.0	21.6
220204		-100.	11.5	392.	43.	-10.	-0.03	10.9	-0.01	-0.1	-1.4	7.4
220101	-1.0	-50.	14.1	778.	-50.	21.	-0.03	31.2	-0.01	-0.1	-1.2	-0.2
220102	-1.0	-50.	11.5	587.	1454.	16.	-0.03	-1.5	-0.01	-0.1	-8.4	181.
220103	-1.0	-50.	8.5	500	1098.	-10.	-0.03	2.0	-0.01	-0.1	15.8	9.9
220301	-1.0	-50.	11.0	871.	-50.	19.	-0.03	11.7	-0.01	-0.1	-1.2	-0.2
220302	-1.0	92.	7.5	509.	454.	22.	-0.03	3.4	-0.01	-0.1	-8.4	92.3
220303	-1.0	-50.	6.8	462.	582.	-10.	-0.03		-0.01	-0.1	-0.5	14.0
220304		-100.	11.6	446.	378.	11.	-0.03	7.5	-0.01	-0.1	6.0	3.7
221101	-1.0	-50	13.0	581.	-50.	24.	-0.03	17.8	-0.01	-0.1	1.3	-0.2

TABLE B-1. Continued

SAMPLE NUMBER	HG UG/L-HG	NI UG/L-NI	K MG/L-K	NA MG/L-NA	ZN UG/L-ZN	SE UG/L-SE	ENDRIN NG/L	LINDANE NG/L	METHOXY-CHLOR NG/L	TOXA-PHENE NG/L	2,4-D NG/L	2,4,5 TP SILVEX NG/L
221102	-1.0	58.	9.5	530.	48.	17.	-0.03	-1.5	-0.01	-0.1	-8.4	77.8
221103	-1.0	-50.	9.4	619.	96.	18.	-0.03	11.0	-0.01	-0.1	10.0	11.2
221104		-100.	14.0	538.	36.	11.	-0.03	8.4	-0.01	-0.1	-1.4	
220501	-1.0	-50.	17.1	592.	-50.	29.	-0.03	8.8	-0.01	-0.1	1.8	-0.2
220502	-1.0	92.	17.7	617.	209.	22.	-0.03	2.6	-0.01	-0.1	-8.4	44.5
220503	-1.0	-50.	13.0	602.	1055.	15.	-0.03	23.6	-0.01	-0.1	13.0	9.8
220504		-100.	18.6	567.	186.	78.	-0.03	44.6	-0.01	-0.1	-1.4	9.0
220401	-1.0	-50.	15.7	557.	72.	30.	-0.03	4.5	-0.01	-0.1	1.6	-0.2
220402	-1.0	75.	16.0	646.	27.	23.	-0.03	2.7	-0.01	-0.1	-8.4	77.2
220403	-1.0	-50.	10.0	653.	554.	12.	-0 03	42.9	-0.01	-0.1	33.8	19.3
221201	-1.0	-50.	10.1	350.	-50.	-10.	-0.03	12.2	-0.01	-0.1	2.0	-0.2
221202	-1.0	-50.	5.5	361.	39.	10.	-0.03	2.7	-0.01	-0.1	-8.4	87.0
221203	-1.0	-50.	6.7	331.	110.	-10.	-0.03	-0.4	-0.01	-0.1	5.7	10.3
221204		-100.	10.1	307.	93.	-10.	-0.03	4.9	-0.01	-0.1	-1.4	23.9
221301	-1.0	-50.	11.3	796.	-50.	18.	-0.03	6.6	-0.01	-0.1	-1.2	-0.2
221302	-1.0	51.	5.2	730.	441.	20.	-0.03	-1.5	-0.01	-0.1	-8.4	41.4
221303	-1.0	-50.	6.7	492.	511.	-10.	-0.03	82.2	-0.01	-0.1	-0.5	77.4
221701	-1.0	-50.	8.8	393.	-50.	-10.	-0.03	6.7	-0.01	-0.1	1.5	-0.2
221702	-1.0	64.	6.0	404.	-20.	11.	-0.03	-1.5	-0.01	-0.1	-8.4	74.9
221703	-1.0	-50.	4.0	378.	53.	-10.	-0.03	2.7	-0.01	-0.1	-0.5	166.
221704		-100.	10.3	354.	36.	-10.	-0.03	14.0	-0.01	-0.1	4.4	14.8
221001	-1.0	-50.	24.0	697.	-50.	50.	-0.03	3.1	-0.01	-0.1	-1.2	-0.2
221002	-1.0	71.	20.0	772.	48.	41.	-0.03	-1.5	-0.01	-0.1	-8.4	49.1
221003	-1.0	-50.	13.0	663.	368.	22.	-0.03	6.7	-0.01	-0.1	26.0	11.5
221004		-100.	19.3	702.	72.	31.	-0.03		-0.01	-0.1	-1.4	25.7

TABLE B-1. Continued

SAMPLE NUMBER	HG UG/L-HG	NI UG/L-NI	K MG/L-K	NA MG/L-NA	ZN UG/L-ZN	BE UG/L-BE	ENDRIN NG/L	LINDANE NG/L	METHOXY-CHLOR NG/L	TOXA-PHENE NG/L	2,4-D NG/L	2,4,5 TP SILVEX NG/L
221901	-1.0	-50.	14.2	314.	-50.	10.	-0.03	12.3	-0.01	-0.1	1.5	-0.2
221902	-1.0	92.	18.7	405.	61.	9.	-0.03	-1.5	-0.01	-0.1	-8.4	70.1
221903	-1.0	-50.	8.3	339.	161.	-10.	-0.03	7.5	-0.01	-0.1	75.9	184.0
221904		-100.	14.6	286.	64.	11.	-0.03	1.5	-0.01	-0.1	-1.4	2.4
220701	-1.0	-50.	8.2	941.	-50.	64.	-0.03	25.4	-0.01	-0.1	-1.2	0.2
220702	-1.0	78.	14.9	704.	54.	36.	-0.03	-1.5	-0.01	-0.1	-8.4	59.9
220703	-1.0	-50.	9.1	771.	904.	29.	-0.03	3.4	-0.01	-0.1	26.6	17.7
220601	-1.0	-50.	10.2	697.	-50.	29.	-0.03	12.2	-0.01	-0.1	1.7	-0.2
220602	-1.0	-50.	7.0	904.	-20.	20.	-0.03	-1.5	-0.01	-0.1	-8.4	69.0
220603	-1.0	-50.	5.8	932.	239.	19.	-0.03	5.4	-0.01	-0.1	15.7	9.8
220604		-100.		1010.	43.	23.	-0.03	11.9	-0.01	-0.1	26.6	22.8
220801	-1.0	-50.	9.6	973.	58.	36.	-0.03	57.2	-0.01	-0.1	-1.2	-0.2
220802	-1.0	-50.	4.5		21.	19.	-0.03	-1.5	-0.01	-0.1	-8.4	70.6
220803	-1.0	-50.	5.5	962.	160.	20.	-0.03	6.1	-0.01	-0.1	11.1	19.0
220804		-100.	12.3	980.	68.	25.	-0.03	2.3	-0.01	-0.1	9.6	7.2
220901	-1.0	-50.	8.3	352.	-50.	10.	-0.03	4.0	-0.01	-0.1	-1.2	-0.2
220902	-1.0	-50.	6.7	335.	25.	9.	-0.03	-1.5	-0.01	-0.1	-8.4	84.9
220903	-1.0	-50.	4.6	331.	68.	-10.	-0.03	5.7	-0.01	-0.1	-0.5	27.1
220904		-100.	6.2	313.	22.	11.	-0.03	15.3	-0.01	-0.1	-1.4	-0.3
222001	-1.0	-50.	13.4	396.	-50.		-0.03	3.5	-0.01	-0.1	-1.2	-0.2
222002	-1.0	71.	9.8	413.	35.		-0.03	2.1	-0.01	-0.1	-8.4	57.8
222003	-1.0	-50.	7.5	432.	232.	28.	-0.03	17.4	-0.01	-0.1	67.9	126.0
222004		-100.	15.8	392.	100.	20.	-0.03	3.6	-0.01	-0.1	-1.4	11.1
224101		-50.	34.0	730.	-50.							
224104		-100.					-0.03		-0.01	-0.1		

TABLE B-1. Continued

SAMPLE NUMBER	HG UG/L-HG	NI UG/L-NI	K MG/L-K	NA MG/L-NA	ZN UG/L-ZN	SE UG/L-SE	ENDRIN NG/L	LINDANE NG/L	METHOXY-CHLOR NG/L	TOXA-PHENE NG/L	2,4-D NG/L	2,4,5 TP SILVEX NG/L
224201		-50.	11.0	730.	80.							
224301		-50.	23.0	581.	-50.							
224304		-100.					-0.03		-0.01	-0.1		

TABLE B-2. SOIL DATA

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	PH	INORGANIC NITROGEN UG/GM-N	TOTAL ORGANIC NITROGEN UG/GM-N	TOTAL PHOSPHORUS UG/GM-P	AVAILABLE PHOSPHORUS UG/GM-P	TOTAL SULFUR UG/GM-S
21111	8/ 2/76	0.01	7.7	92.9	9035.	563.	68.	455.
21131	11/20/76	0.01	7.3	17.2	1900.	908.	144.	416.
21112	8/ 2/76	0.03	7.7	86.6	3427.	561.	78.	253.
21132	11/20/76	0.03	6.8	9.3	754.	540.	75.	218.
21113	8/ 2/76	0.10	8.0	82.2	1429.	548.	48.	271.
21133	11/20/76	0.10	6.9	13.5	575.	485.	61.	202
21114	8/ 2/76	0.30	7.9	47.7	861.	530.	0.	171.
21134	11/20/76	0.30	7.0	5.5	802.	601.	50.	180.
21115	8/ 2/76	1.00	8.8	33.9	470.	554.	22.	166.
21135	11/20/76	1.00	7.9	6.3	438.	545.	15.	168.
21116	8/ 2/76	3.00	8.2	33.0	368.	403.	12.	143.
21136	11/20/76	3.00	8.1	5.5	197.	452.	3.	146.
21211	8/ 2/76	0.01	7.4	45.7	1873.	608.	96.	310.
21231	11/20/76	0.01	7.1	8.1	899.	664.	65.	198.
21212	8/ 2/76	0.03	7.5	63.0	1147.	597.	69.	216.
21232	11/20/76	0.03	6.8	5.8	1396.	667.	102.	308.
21213	8/ 2/76	0.10	7.5	54.4	852.	575.	67.	200
21233	11/20/76	0.10	6.8	7.9	1042.	682.	111.	369
21214	8/ 2/76	0 30	7.6	45.9	259.	489.	28.	160.
21234	11/20/76	0.30	6.8	6.0	322.	445.	47.	211.
21215	8/ 2/76	1.00	8.4	23.9	478.	518.	16.	154.
21235	11/20/76	1.00	8.3	3.7	242.	481.	18.	128.
21216	8/ 2/76	3.00	8.5	32.5	473.	605.	7.	206.
21236	11/20/76	3.00	8.8	4.2	223.	421.	15.	122.
21311	8/ 2/76	0.01	7.8	50.7	1063.	590.	80.	206.

TABLE B-2. Continued

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	PH	INORGANIC NITROGEN UG/GM-N	TOTAL ORGANIC NITROGEN UG/GM-N	TOTAL PHOSPHORUS UG/GM-P	AVAILABLE PHOSPHORUS UG/GM-P	TOTAL SULFUR UG/GM-S
21331	11/20/76	0.01	7.0	4.8	1955.	757.	140.	443.
21312	8/ 2/76	0.03	7.4	65.1	665.	513.	46.	137.
21332	11/20/76	0.03	7.3	5.8	1450.	713.	118.	468.
21313	8/ 2/76	0.10	7.4	60.0	359.	462.	35.	228.
21333	11/20/76	0.10	7.0	4.9	1251.	767.	154.	361.
21314	8/ 2/76	0.30	7.6	54.0	462.	574.	36.	242.
21334	11/20/76	0.30	7.1	8.6	564.	536.	68.	238.
21315	8/ 2/76	1.00	8.9	37.0	269.	513.	15.	223.
21335	11/20/76	1.00	9.0	5.1	258.	776.	24.	219.
21316	8/ 2/76	3.00	8.7	31.0	272.	483.	6.	149.
21336	11/20/76	3.00	8.3	5.5	112.	387.	21.	171.
22111	8/ 2/76	0.01	7.9	54.8	9963.	841.	84.	411.
22131	11/20/76	0.01	7.8	16.5	4427.	1108.	184.	466.
22112	8/ 2/76	0.03	7.8	34.3	6771.	719.	81.	207.
22132	11/20/76	0.03	7.4	11.5	1856.	999.	138.	418.
22113	8/ 2/76	0.10	8.0	45.6	2258.	680.	69.	265.
22133	11/20/76	0.10	7.6	12.0	1808.	675.	72.	311.
22114	8/ 2/76	0.30	9.2	43.7	860.	508.	20.	240.
22134	11/20/76	0.30	8.2	8.3	924.	604.	37.	280.
22115	8/ 2/76	1.00	8.8	35.4	369.	447.	12.	185.
22135	11/20/76	1.00	8.6	7.3	249.	513.	12.	174.
22116	8/ 2/76	3.00	8.8	36.3	268.	450.	4	149.
22136	11/20/76	3.00	8.7	11.4	239.	515.	5.	165.
22211	8/ 2/76	0.01	7.9	50.2	2863.	806.	85.	430.
22231	11/20/76	0.01	7.8	11.6	5028.	768.	120.	429.

TABLE B-2. Continued

SAMPLE NUMBER	COLLECTION DATE	DEPTH M	PH	INORGANIC NITROGEN UG/GM-N	TOTAL ORGANIC NITROGEN UG/GM-N	TOTAL PHOSPHORUS UG/GM-P	AVAILABLE PHOSPHORUS UG/GM-P	TOTAL SULFUR UG/GM-S
22212	8/ 2/76	0.03	7.3	133.7	1753.	683.	78.	196.
22232	11/20/76	0.03	7.7	46.2	2193.	699.	111.	411.
22213	8/ 2/76	0.10	7.6	83.1	2254.	669.	60.	294.
22233	11/20/76	0.10	7.7	15.9	1822.	783.	95.	417.
22214	8/ 2/76	0.30	9.0	30.8	575.	594.	25.	206.
22234	11/20/76	0.30	8.1	4.9	487.	541.	37.	212.
22215	8/ 2/76	1.00	8.8	79.7	529.	604.	21.	221.
22235	11/20/76	1.00	8.7	5.2	402.	555.	12.	202.
22216	8/ 2/76	3.00	8.8	38.2	169.	403.	9.	151.
22236	11/20/76	3.00	8.2	7.8	172.	371.	3.	164.
22311	8/ 2/76	0.01	7.4	70.9	1947.	705.	69.	289.
22331	11/20/76	0.01	7.7	14.1	2966.	826.	110.	490.
22312	8/ 2/76	0.03	7.8	53.2	1761.	665.	65.	238.
22332	11/20/76	0.03	7.2	21.5	897.	819.	45.	416.
22313	8/ 2/76	0.10	7.7	55.0	1955.	723.	55.	326
22333	11/20/76	0.10	7.6	13.3	1248.	832.	99.	384.
22314	8/ 2/76	0.30	8.0	33.1	974.	539.	16.	372.
22334	11/20/76	0.30	8.2	24.7	789.	659.	49.	272.
22315	8/ 2/76	1.00	8.5	33.9	374.	607.	13	411.
22335	11/20/76	1.00	8.4	14.6	449.	600.		264.
22316	8/ 2/76	3.00	8.6	18.9	283.	459.	9.	183.
22336	11/20/76	3.00	8.5	9.5	201.	499.		216.

TABLE B-2. Continued

SAMPLE NUMBER	CATION EX-CAP MEQ/1000	EXTR. AL UG/GM	EXTR. B UG/GM	EXTR. CD UG/GM	EXTR. CO UG/GM	EXTR. CR UG/GM	EXTR. CU UG/GM	EXTR. FE UG/GM	EXTR. PB UG/GM	EXCH. MG MG/GM	EXTR. MN UG/GM
21111	9.	-3.0	1.34	0.05	0.45	-0.02	3.0	37.	2.3	0.81	41.
21131	23.	19.0	2.15	-0.02	0.80	-0.13	0.5	28.		0.62	34.
21112	5.	-3.0	1.42	0.08	0.48	0.03	1.4	39.	-1.2	0.74	41.
21132	12.	39.0	1.19	-0.02	0.60	-0.13	2.2	54.		0.50	36.
21113	4.	-3.0	0.93	0.03	0.36	0.06		40.	-1.2	0.68	34.
21133	8.	98.0	1.05	-0.02	-0.12	-0.13	0.7	20.		0.43	11.
21114	8.	-3.0	0.99	0.06	0.40	-0.02	1.9	41.	-1.2	0.67	34.
21134	12.	107.0	0.79	-0.02	-0.12	-0.13	1.6	26.		0.40	14.
21115	6.	-3.0	0.63	0.06	0.33	-0.02	3.7	30.	-1.2	0.69	25.
21135	12.	84.0	0.70	-0.02	-0.12	-0.13	1.4	35.		0.48	25.
21116	8.	-3.0	0.54	0.06	0.17	-0.02	2.1	53.	-1.2	0.62	27.
21136	15.	-10.0	0.69	-0.02	-0.12	-0.13	8.8	22.		0.43	14.
21211	8.	-3.0	1.26	0.02	0.20	-0.02	2.2	61.	-1.2	0.83	37.
21231	11.	78.0	1.96	-0.02	0.55	-0.13	0.7	42.		0.54	37.
21212	7.	-3.0	1.14	0.06	0.17	-0.02	3.7	64.	1.6	0.78	26.
21232	17.	104.0	1.48	-0.02	0.55	-0.13	0.7	43.		0.65	40.
21213	7.	3.0	1.54	0.04	0.27	-0.02	3.0	66.	-1.2	0.73	22.
21233	18.	130.0	1.39	-0.02	-0.12	-0.13	0.5	38.		0.46	22.
21214	5.	-3.0	0.78	-0.02	0.30	-0.02	0.9	28.	1.6	0.62	19.
21234	14.	98.0	0.91	-0.02	-0.12	-0.13	0.9	35.		0.40	15.
21215	6.	-3.0	0.77	0.04	0.48	-0.02	2.5	47.	-1.2	0.64	31.
21235	12.	52.0	0.90	-0.02	-0.12	-0.13	1.0	18.		0.36	11.
21216	11.	-3.0	0.67	0.06	0.30	-0.02	4.4	45.	2.0	0.77	29.
21236	8.	32.0	0.70	-0.02	-0.12	-0.13	1.7	15.		0.48	14.
21311	17.	-3.0	1.41	0.06	0.24	-0.02	1.4	41.	-1.2	0.79	27.

TABLE B-2. Continued

SAMPLE NUMBER	CATION EX-CAP MEQ/100G	EXTR. AL UG/GM	EXTR. B UG/GM	EXTR. CD UG/GM	EXTR. CO UG/GM	EXTR. CR UG/GM	EXTR. CU UG/GM	EXTR. FE UG/GM	EXTR. PB UG/GM	EXCH. MG MG/GM	EXTR. MN UG/GM
21331	13.	32.0	2.09	-0.02	0.65	-0.13	0.8	43.		0.55	49.
21312	9.	-3.0	0.97	0.05	0.25	-0.02	1.8	48.	-1.2	0.72	28.
21332	23.	65.0	2.18	-0.02	0.26	-0.13	0.6	40.		0.57	36.
21313	9.	-3.0	1.09	0.03	0.14	-0.02	1.3	42.	-1.2	0.68	12.
21333	11.	42.0	1.43	-0.02	0.31	-0.13	1.2	49.		0.58	23.
21314	11.	-3.0	0.79	0.03	-0.12	-0.02	0.4	32.	-1.2	0.72	11.
21334	10.	133.0	0.96	-0.02	-0.12	-0.13	1.1	52.		0.50	27.
21315	10.	-3.0	0.36	0.03	0.17	-0.02	0.9	17.	-1.2	0.65	15.
21335	7.	-10.0	0.75	-0.02	-0.12	-0.13	0.4	12.		0.44	7.
21316	9.	-3.0	0.80	0.04	-0.12	-0.02	0.9	21.	-1.2	1.00	11.
21336	7.	58.0	0.41	-0.02	-0.12	-0.13	0.6	16.		0.34	11.
22111	31.	-3.0	1.95	0.06	0.30	-0.02	11.0	76.	2.4	1.30	43.
22131	26.	26.0	4.89	-0.02	-0.12	-0.13	3.6	46.		0.71	38.
22112	39.	-3.0	1.60	0.08	0.13	-0.02	9.5	54.		1.20	33.
22132	23.	65.0	2.21	0.03	0.70	-0.13	2.5	66.		0.68	
22113	17.	-3.0	1.29	0.10	-0.12	-0.02	9.3	41.	-1.2	1.00	22.
22133	23.	120.0	1.92	-0.02	-0.12	-0.13	3.9	32.		0.70	32.
22114	16.	-3.0	1.12	0.02	0.24	-0.02	1.7	14.	-1.2	1.30	22.
22134	21.	-10.0	1.23	-0.02	-0.12	-0.13	1.5	18.		0.56	27.
22115	7.	3.0	0.96	0.02	-0.12	-0.02	2.1	27.	-1.2	0.74	7.
22135	10.	-10.0	1.08	-0.02	-0.12	-0.13	1.5	12.		0.58	9.
22116	4.	-3.0	0.81	-0.02	0.17	-0.02	2.4	32.	-1.2	0.73	12.
22136	12.	-10.0	0.94	-0.02	-0.12	-0.13	5.8	10.	0.0	0.72	14.
22211	17.	-3.0	1.57	0.05	0.24	-0.02	2.2	56.	-1.2	1.00	24.
22231	30.	19.0	2.95	-0.02	0.41	-0.13	5.5	40.		0.78	48.

TABLE B-2. Continued

SAMPLE NUMBER	CATION EX-CAP MEQ/100G	EXTR. AL UG/GM	EXTR. B UG/GM	EXTR. CD UG/GM	EXTR. CO UG/GM	EXTR. CR UG/GM	EXTR. CU UG/GM	EXTR. FE UG/GM	EXTR. PB UG/GM	EXCH. MG MG/GM	EXTR. MN UG/GM
22212	21.	-3.0	1.29	0.08	0.16	-0.02	3.0	59.	1.2	0.90	36.
22232	23.	-10.0	1.56	-0.02	-0.12	-0.13	1.1	24.		0.69	14.
22213	24.	3.0	1.54	0.13	0.67	-0.02	2.8	56.	-1.2	0.55	35.
22233	26.	19.0	1.66	-0.02	-0.12	-0.13	2.5	32.		0.65	19.
22214	8.	3.5	0.97	1.12	0.17	-0.02	2.6	44.	-1.2	0.90	27.
22234	18.	-10.0	0.96	-0.02	-0.12	-0.13	0.9	18.		0.60	11.
22215	17.	-3.0	0.91	0.03	0.45	-0.02	4.0	42.	-1.2	1.40	37.
22235	10.	-10.0	1.10	-0.02	-0.12	-0.13	1.1	11.		0.79	8.
22216	8.	-3.0	0.68	0.07	0.61	-0.02		58.	-1.2	0.43	35.
22236	7.	-10.0	0.34	-0.02	-0.12	-0.13	1.7	25.		0.46	8.
22311	6.	-3.0	0.80	0.05	0.27	-0.02		75.	-1.2	0.96	42.
22331	27.	39.0	4.20	-0.02	-0.12	-0.13	2.5	46.		0.73	24.
22312	7.	-3.0	0.54	0.04	0.21	-0.02	5.4	54.	-1.2	0.92	20.
22332	24.	-10.0	2.09	-0.02	-0.12	-0.13	1.1	39.		0.58	19.
22313	11.	-3.0	0.74	0.05	0.33	0.02		74.	-1.2	0.83	24.
22333	22.	-10.0	1.59	-0.02	-0.12	-0.13	1.5	35.		0.59	16.
22314	11.	3.0	0.86	0.02	0.39	-0.02	3.8	61.	-1.2	0.63	28.
22334	21.	-10.0	1.01	-0.02	-0.12	-0.13	0.7	12.		0.60	7.
22315	11.	-3.0	0.75	0.04	0.39	0.05		79.	-1.2	1.10	35.
22335	21.	-10.0	0.83	-0.02	-0.12	-0.13	8.0	27.		0.80	26.
22316	8.	-3.0	0.47	0.03	-0.12	-0.02	2.0	60.	-1.2	0.87	19.
22336	20.	-10.0	0.79	-0.02	-0.12	-0.13	5.0	33.		0.76	28.

TABLE B-2. Continued

SAMPLE NUMBER	EXTR. NI UG/GM	EXCH. K MG/GM	EXCH. NA MG/GM	EXTR. ZN UG/GM	ENDRIN NG/GM	LINDANE NG/GM	METHOXYCHLOR NG/GM	TOXAPHENE NG/GM	2,4-D NG/GM	SILVEX NG/GM	TOTAL AL MG/GM	TOTAL CD UG/GM	TOTAL CA UG/GM
21111	0.8	0.2	0.28	9.00	-0.6	58.82	-0.01	-0.6	0.49	2.05	53.0	-2.0	5.2
21131	0.6	0.6	0.32	5.77	-0.6	0.99	-0.01	-0.6	0.35	3.43	22.0	-5.0	4.2
21112	0.8	0.3	0.24	6.50	-0.6	13.20	-0.01	-0.6	0.54	1.23	53.0	-2.0	4.1
21132	2.6	0.4	0.35	3.35	-0.6	0.13	-0.01	-0.6	1.18	4.35	18.0	-5.0	2.1
21113	0.9	0.2	0.22	8.50	-0.6	29.95	-0.01	-0.6	0.39	1.12	53.0	-2.0	3.9
21133	0.9	0.4	0.47	0.85	-0.6	77.70	-0.01	-0.6	2.45	4.32	25.0	-5.0	3.1
21114	1.0	0.3	0.23	4.80							57.0	-2.0	3.9
21134	0.9	0.5	0.32	1.27							24.0	-5.0	3.1
21115	0.8	0.3	0.28	1.00							58.0	-2.0	5.8
21135	1.4	0.3	0.36	0.48							32.0	-5.0	5.4
21116	1.6	0.2	0.25	0.50							52.0	-2.0	5.5
21136	1.0	0.1	0.32	1.61							30.0	-5.0	7.1
21211	0.4	0.2	0.29	8.20	-0.6	9.79	-0.01	-0.6	1.50	1.12	49.0	-2.0	4.2
21231	1.1	0.3	0.27	2.59	-0.6	1.24	-0.01	-0.6	1.85	4.01	13.0	-5.0	1.6
21212	0.6	0.3	0.26	13.00	-0.6	7.12	-0.01	-0.6	0.86	0.92	47.0	-2.0	4.1
21232	1.1	0.3	0.42	4.33	-0.6	1.04	-0.01	-0.6	0.99	5.26	15.0	-5.0	0.5
21213	0.6	0.3	0.23	7.00	-0.6	3.79	-0.01	-0.6	0.58	0.75	49.0	-2.0	4.3
21233	0.8	0.3	0.31	2.93	-0.6	0.80	-0.01	-0.6	1.63	3.41	8.6	-5.0	1.5
21214	0.4	0.3	0.15	0.80							44.0	-2.0	4.4
21234	1.0	0.3	0.27	0.33							20.0	-5.0	2.5
21215	0.8	0.3	0.28	-0.50							50.0	-2.0	6.4
21235	0.7	0.1	0.27	-0.12							19.0	-5.0	2.5
21216	1.1	0.2	0.30	2.70							47.0	-2.0	8.4
21236	0.8		0.36	-0.12							10.0	-5.0	2.2
21311	0.8	0.3	0.26	6.20	-0.6	3.84	-0.01	-0.6	3.05	1.28	43.0	-2.0	4.9

TABLE B-2. Continued

SAMPLE NUMBER	EXTR. NI UG/GM	EXCH. K MG/GM	EXCH. NA MG/GM	EXTR. ZN UG/GM	ENDRIN NG/GM	LINDANE NG/GM	METHOXYCHLOR NG/GM	TOXAPHENE NG/GM	2,4-D NG/GM	SILVEX NG/GM	TOTAL AL MG/GM	TOTAL CD UG/GM	TOTAL CA UG/GM
21331	0.8	0.2	0.30	5.77	-0.6	3.26	-0.01	-0.6	0.84	8.97	9.5	-5.0	0.9
21312	0.7	0.2	0.23	5.10	-0.6	12.96	-0.01	-0.6	4.92	1.31	46.0	-2.0	5.1
21332	0.9	0.1	0.32	3.77	-0.6	-0.13	-0.01	-0.6	12.40	12.40	7.7	-5.0	1.6
21313	0.5	0.3	0.22	5.50	-0.6	59.02	-0.01	-0.6	0.97	0.94	43.0	-2.0	5.4
21333	1.0	0.2	0.38	4.03	-0.6	1.98	-0.01	-0.6	1.40	3.34	5.1	-5.0	0.7
21314	0.5	0.3	0.23	3.20							74.0	-2.0	4.6
21334	1.6	0.2	0.32	1.23							6.0	-5.0	0.3
21315	0.7	0.2	0.27	1.00							65.0	-2.0	7.9
21335	0.7	0.2	0.27	-0.12							9.5	-5.0	1.3
21316	0.9	0.1	0.51	-0.50							66.0	-2.0	11.0
21336	0.6	0.2	0.25	-0.12							5.6	-5.0	1.4
22111	1.1	0.6	0.53	12.00	-0.6	20.76	-0.01	-0.6	2.93	1.25	74.0	-2.0	4.3
22131	1.1	0.9	0.87	9.63	-0.6	-0.13	-0.01	-0.6	6.11	6.25	5.1	-5.0	0.5
22112	1.0	0.5	0.61	5.00	-0.6	3.90	-0.01	-0.6	1.98	1.35	61.0	-2.0	4.0
22132	1.4	0.6	0.89	4.48	-0.6	0.44	-0.01	-0.6	7.10	12.80	9.5	-5.0	0.7
22113	1.0	0.5	0.75	1.50	-0.6	4.01	-0.01	-0.6	2.49	1.16	92.0	-2.0	4.5
22133	1.3	0.5	0.62	3.80	-0.6	0.19	-0.01	-0.6	3.69	3.08	12.0	-5.0	0.7
22114	0.4	0.3	0.75	-0.50							71.0	-2.0	6.7
22134	1.4	0.3	0.58	-0.12							22.0	-5.0	3.5
22115	0.4	0.2	0.51	-0.50							64.0	-2.0	6.3
22135	0.5	0.1	0.35	-0.12							19.0	-5.0	4.4
22116	-0.2	0.1	0.43	-0.50							70.0	-2.0	11.0
22136	0.6	0.1	0.37	0.54							26.0	-5.0	7.6
22211	0.9	0.6	0.74	2.80	-0.6	17.14	-0.01	-0.6	2.81	1.90	72.0	-2.0	3.2
22231	1.2	0.9	0.82		-0.6	1.43	-0.01	-0.6	10.00	9.68	17.0	-5.0	1.2

TABLE B-2. Continued

SAMPLE NUMBER	EXTR. NI UG/GM	EXCH. K MG/GM	EXCH. NA MG/GM	EXTR. ZN UG/GM	ENDRIN NG/GM	LINDANE NG/GM	METHOXYCHLOR NG/GM	TOXAPHENE NG/GM	2,4-D NG/GM	SILVEX NG/GM	TOTAL AL MG/GM	TOTAL CD UG/GM	TOTAL CA UG/GM
22212	0.8	0.5	0.59	4.50	-0.6	41.47	-0.01	-0.6	1.35	1.82	85.0	-2.0	6.5
22232	1.0	0.7	0.73	1.38	-0.6	0.47	-0.01	-0.6	5.08	13.30	23.0	-5.0	1.9
22213	0.9	0.5	0.64	9.90	-0.6	7.52	-0.01	-0.6	1.44	1.01	55.0	-2.0	4.5
22233	1.0	0.8	0.64	4.03	-0.6	-0.13	-0.01	-0.6	0.92	6.48	8.6	-5.0	1.2
22214	0.6	0.3	0.52	-0.50							79.0	-2.0	4.6
22234	0.8	0.4	0.45	-0.12							11.0	-5.0	2.1
22215	0.6	0.4	0.62	-0.50							90.0	-2.0	5.5
22235	0.7		0.45	-0.12							11.0	-5.0	3.4
22216	0.9	0.1	0.35	2.50							72.0	-2.0	6.4
22236	0.6	0.2	0.25	-0.12							9.0	-5.0	1.8
22311	1.4	0.7	0.74	10.00	-0.6	6.40	-0.01	-0.6	2.39	1.72	64.0	-2.0	4.5
22331	1.2	0.7	0.90	5.09	-0.6	0.88	-0.01	-0.6	1.65	3.55	18.0	-5.0	2.0
22312	0.6	0.6	0.65	3.40	-0.6	5.17	-0.01	-0.6	3.17	1.67	90.0	-2.0	4.7
22332	1.1	0.5	0.70	1.50	-0.6	-0.13	-0.01	-0.6	0.74	7.21	13.0	-5.0	2.0
22313	0.9	0.5	0.80	4.70	-0.6	9.12	-0.01	-0.6	1.50	1.58	71.0	-2.0	5.2
22333	1.2	0.5	0.70	1.53	-0.6	77.70	-0.01	-0.6	0.08	13.80	10.0	-5.0	1.5
22314	0.4	0.4	0.49	0.50							93.0	-2.0	12.0
22334	0.7	0.4	0.66	-0.12							9.5	-5.0	2.9
22315	0.9	0.5	0.74	6.00							83.0	-2.0	11.0
22335	1.2	0.2	0.70	0.91							21.0	-5.0	7.0
22316	0.6	0.1	0.39	4.00							63.0	-2.0	7.8
22336	0.9	0.2	0.54	0.17							22.0	-5.0	7.1

TABLE B-2. Continued

SAMPLE NUMBER	TOTAL CO UG/GM	TOTAL CR UG/GM	TOTAL CU UG/GM	TOTAL FE MG/GM	TOTAL PB UG/GM	TOTAL MG MG/GM	TOTAL MN UG/GM	TOTAL HG UG/GM	TOTAL NI UG/GM	TOTAL K MG/GM	TOTAL NA MG/GM	TOTAL ZN UG/GM	TOTAL AS UG/GM	TOTAL SE UG/GM
21111	-5.0	22.	7.8	4.9	-10.0	11.0	234.	-3.00	13.00	5.1	15.0	92.	4.	-1.0
21131	-2.0	34.	10.0	12.0	-10.0	4.4	228.	-0.05	-10.00	9.0	9.0	151.	5.	-1.0
21112	6.0	23.	7.2	4.9	-10.0	4.5	248.	-3.00	16.00	5.3	14.0	58.	3.	-1.0
21132	6.0	32.	11.0	13.0	-10.0	4.4	228.	-0.05	-10.00	9.0	11.0	59.	5.	-1.0
21113	6.0	21.	6.8	4.8	-10.0	4.5	221.	-3.00	13.00	5.1	15.0	60.	3.	-1.0
21133	6.0	40.	11.0	15.0	-10.0	4.4	260.	-0.05	12.00	9.0	9.8		4.	-1.0
21114	7.0	27.	8.6	4.5	-10.0	5.6	226.	-3.00	17.00	5.2	14.0	62.	5.	-1.0
21134	-2.0	46.	9.3	13.0	-10.0	4.7	212.	-0.05	12.00	9.0	11.0	63.	5.	-1.0
21115	5.0	36.	11.0	5.0	-10.0	6.4	273.	-3.00	13.00	5.4	14.0	76.	5.	-1.0
21135	6.0	47.	13.0	16.0	-10.0	5.9	281.	-0.05	16.00	10.0	10.0	54.	6.	-1.0
21116	-5.0	27.	10.0	4.8	-10.0	5.8	228.	-3.00	16.00	4.9	13.0	70.	4.	-1.0
21136	4.0	46.	18.0	15.0	-10.0	5.3	251.	-0.05	-10.00	9.0	11.0	74.	7.	-1.0
21211	-5.0	17.	-2.0	4.5	-10.0	5.6	153.	-3.00	6.70	5.0	14.0	113.	6.	-1.0
21231	6.0	33.	8.0	11.0	-10.0	4.0	178.	-0.05.	-10.00	8.0	11.0	55.	4.	-1.0
21212	-5.0	21.	6.3	4.4	-10.0	4.5	169.	-3.00	6.60	4.8	13.0	55.	5.	-1.0
21232	6.0	30.	9.3	12.0	-10.0	4.3	218.	-0.05	-10.00	7.0	11.0	58.	5.	-1.0
21213	5.0	21.	7.3	4.7	-10.0	4.9	198.	-3.00	8.20	5.0	14.0	77.	4.	-1.0
21233	-2.0	30.	11.0	11.0	-10.0	3.8	170.	-0.05	-10.00	6.0	8.7	45.	4.	-1.0
21214	-5.0	20.	5.8	4.7	-10.0	5.0	179.	-3.00	10.00	4.6	14.0	53.	4.	-1.0
21234	-2.0	31.	6.7	13.0	-10.0	3.5	194.	-0.05	-10.00	7.0	9.5	43.	5	-1.0
21215	6.0	26.	15.0	4.9	-10.0	6.8	243.	-3.00	14.00	4.8	12.0	88.	5.	-1.0
21235	6.0	29.	12.0	12.0	-10.0	2.7	194.	-0.05	-10.00	6.0	10.0	43.	6.	-1.0
21216	8.0	27.	19.0	5.0	-10.0	7.9	276.	-3.00	20.00	4.8	12.0	72.	7.	-1.0
21236	-2.0	26.	12.0	10.0	-10.0	2.7	156.	-0.05	-10.00	6.0	10.0	34.	5.	-1.0
21311	-5.0	16.	10.0	4.7	-10.0	5.7	202.	-3.00	13.00	4.9	12.0	39.	5.	-1.0

TABLE B-2. Continued

SAMPLE NUMBER	TOTAL CO UG/GM	TOTAL CR UG/GM	TOTAL CU UG/GM	TOTAL FE MG/GM	TOTAL PB UG/GM	TOTAL MG MG/GM	TOTAL MN UG/GM	TOTAL HG UG/GM	TOTAL NI UG/GM	TOTAL K MG/GM	TOTAL NA MG/GM	TOTAL ZN UG/GM	TOTAL AS UG/GM	TOTAL SE UG/GM
21331	-2.0	26.	7.4	11.0	-10.0	3.6	210.	-0.05	-10.00	6.0	10.0	47.	4.	-1.0
21312	6.0	27.	8.2	4.7	-10.0	11.0	198.	-3.00	9.70	5.2	14.0	52.	3.	-1.0
21332	-2.0	40.	13.0	15.0	-10.0	5.8	271.	-0.05	-10.00	8.0	7.7	58.	6.	-1.0
21313	5.0	26.	9.0	4.8	-10.0	5.2	202.	-3.00	13.00	4.9	13.0	91.	5.	-1.0
21333	-2.0	28.	8.0	11.0	-10.0	2.7	170.	-0.05	13.00	7.0	11.0	43.	4.	-1.0
21314	6.0	32.	12.0	4.8	-10.0	6.0	238	-3.00	16.00	5.4	12.0	93.	5.	-1.0
21334	-2.0	29.	9.3	10.0	-10.0	2.7	167.	-0.05	12.00	6.0	8.9	42.	4.	-1.0
21315	6.0	26.	11.0	4.8	-10.0	6.5	224.	-3.00	14.00	5.0	12.0	81.	5.	-1.0
21335	-2.0	28.	10.0	12.0	-10.0	2.7	308.	-0.05	14.00	6.0	14.0	38.	5.	-1.0
21316	6.0	29.	11.0	4.9	-10.0	6.3	221.	-3.00	13.00	4.9	12.0	75.	6.	-1.0
21336	-2.0	26.	6.1	10.0	-10.0	2.5	148.	-0.05	14.00	4.0	9.2	32.	5.	-1.0
22111	6.0	37.	15.0	5.4	-10.0	7.5	321.	-3.00	16.00	5.5	12.0	118.	5.	-1.0
22131	-2.0	27.	15.0	10.0	-10.0	4.0	159.	-0.05	14.00	3.0	5.8	40.	6.	-1.0
22112	7.0	40.	15.0	5.2	-10.0	7.2	320.	-3.00	16.00	4.7	12.0	108	6.	-1.0
22132	-2.0	34.	20.0	15.0	-10.0	4.0	324.	-0.05	19.00	6.0	9.4	61.	7.	-1.0
22113	6.0	38.	16.0	5.4	-10.0	7.7	338.	-3.00	16.00	5.6	11.0	92.	6.	-1.0
22133	6.0	36.	21.0	19.0	-10.0	4.9	425.	-0.05	-10.00	6.0	8.5	64.	9.	-1.0
22114	8.0	32.	14.0	5.5	-10.0	8.3	280.	-3.00	16.00	4.9	11.0	93.	5.	-1.0
22134	6.0	33.	13.0	15.0	-10.0	2.0	283.	-0.05	14.00	7.0	12.0	50.	7.	-1.0
22115	7.0	22.	8.7	5.0	-10.0	7.2	221.	-3.00	14.00	3.9	13.0	73.	3.	-1.0
22135	6.0	35.	16.0	14.0	-10.0	1.0	255.	-0.05	14.00	6.0	12.0	54.	6.	-1.0
22116	6.0	29.	7.7	4.8	-10.0	6.3	221.	-3.00	11.00	5.1	13.0	82.	5.	-1.0
22136	4.0	34.	19.0	16.0	-10.0	4.0	301.	-0.05	14.00	6.0	11.0	58.	7.	-1.0
22211	5.0	26.	13.0	5.0	-10.0	6.9	308.	-3.00	17.00	5.2	12.0	99.	6.	-1.0
22231	6.0	44.	27.0	20.0	-10.0	3.3	343.	-0.05	14.00	7.0	9.2	79.	7.	-1.0

TABLE B-2. Continued

SAMPLE NUMBER	TOTAL CD UG/GM	TOTAL CR UG/GM	TOTAL CU UG/GM	TOTAL FE MG/GM	TOTAL PB UG/GM	TOTAL MG MG/GM	TOTAL MN UG/GM	TOTAL HG UG/GM	TOTAL NI UG/GM	TOTAL K MG/GM	TOTAL NA MG/GM	TOTAL ZN UG/GM	TOTAL AS UG/GM	TOTAL BE UG/GM
22212	5.0	33.	12.0	4.7	-10.0	6.8	290.	-3.00	14.00	5.4	12.0	108.	7.	-1.0
22232	6.0	33.	16.0	16.0	-10.0	4.7	282.	-0.05	21.00	6.0	11.0	57.	8.	-1.0
22213	9.0	35.	17.0	5.3	-10.0	6.4	364.	-3.00	14.00	5.2	11.0	106.	7.	-1.0
22233	6.0	34.	15.0	15.0	-10.0	4.7	239.	-0.05	19.00	6.0	7.8	57.	8.	-1.0
22214	6.0	37.	13.0	5.1	-10.0	7.6	271.	-3.00	16.00	5.2	13.0	77.	6.	-1.0
22234	-2.0	25.	17.0	12.0	-10.0	4.7	180.	-0.05	12.00	6.0	9.3	42.	6.	-1.0
22215	8.0	35.	17.0	5.6	-10.0	9.2	386.	-3.00	17.00	5.5	11.0	98.	6.	-1.0
22235	-2.0	37.	14.0	14.0	-10.0	4.0	194.	-0.05	-10.00	6.0	9.5	46.	6.	-1.0
22216	6.0	30.	12.0	4.9	-10.0	7.6	243.	-3.00	14.00	4.6	13.0	87.	6.	-1.0
22236	4.0	30.	10.0	12.0	-10.0	2.5	131.	-0.05	14.00	5.0	11.0	36.	5.	-1.0
22311	6.0	37.	16.0	5.0	-10.0	8.1	299.	-3.00	17.00	5.0	11.0	88.		
22331	4.0	34.	20.0	16.0	-10.0	4.0	300.	-0.05	14.00	6.0	9.5	62.	7.	-1.0
22312	6.0	29.	17.0	4.9	-10.0	10.0	318.	-3.00	17.00	4.7	12.0	128.	8.	-1.0
22332	-2.0	38.	16.0	14.0	-10.0	3.6	255.	-0.05	-10.00	6.0	8.9	62.	8.	-1.0
22313	5.0	39.	18.0	5.3	-10.0	9.4	355.	-3.00	20.00	4.8	10.0	133.	9.	-1.0
22333	-2.0	33.	13.0	12.0	-10.0	4.4	175.	-0.05	14.00	6.0	13.0	39.	6.	-1.0
22314	6.0	33.	14.0	5.0	-10.0	8.7	304.	-3.00	15.00	4.9	11.0	100.	6.	-1.0
22334	-2.0	32.	13.0	11.0	-10.0	4.4	167.	-0.05	19.00	5.0	9.9	37.	7.	-1.0
22335	6.0	39.	25.0	14.0	-10.0	5.6	287.	-0.05	19.00	7.0	9.1	52.	9.	-1.0
22315	5.0	35.	17.0	5.1	-10.0	11.0	320.	-3.00	17.00	4.6	8.5	121.	7.	-1.0
22316	-5.0	26.	10.0	5.1	-10.0	8.0	205.	-3.00	14.00	4.7	12.0	78.	6.	-1.0
22336	4.0	38.	19.0	14.0	-10.0	4.6	328.	-0.15	19.00	6.0	9.6	53.	5.	-1.0

TABLE B-3. PLANT DATA

SAMPLE NUMBER	COLLECTION DATE	NH4 UG/GM-N	TOTAL ORGN -N MG/GM-N	NO2+NO3 UG/GM-N	TOTAL P MG/GM	TOTAL S UG/GM	TOTAL COLI. #/GM	FECAL COLI. #/GM	AS UG/GM	B UG/GM	CD UG/GM	CA MG/GM	CO UG/GM
2111	6/ 7/76	100.	7. 8	676.	3. 1	929.	43	20	-1.	12. 9	-5.	2. 47	-1.
2113	11/20/76	302.	35. 1	841.	3. 9	1594.	100.	100.	-1.		-5.	3. 32	-2.
2121	6/ 7/76	236.	4. 1	548.	2. 1	1209.	7.	0.	-1.	9. 8	-5.	3. 10	-1.
2123	11/20/76	266.	37. 0	676.	3. 1	1730.	100.	0.	-1.		-5.	4. 02	-2.
2131	6/ 7/76	230.	5. 3	543.	1. 6	959.	0.	0.	-1.	19. 6	-5.	2. 84	-1.
2133	11/20/76	193.	24. 6	609.	2. 4	859.	100.	0.	-1.		-5.	4. 10	-2.
2211	6/ 7/76	812.	15. 6	1101.	2. 4	1029.	3.	0.	-1.	23. 5	-5.	3. 73	-1.
2213	11/20/76	543.	32. 2	794.	2. 6	1581.	100.	0.	-1.		-5.	3. 38	-2.
2221	6/ 7/76	135.	3. 5	541.	3. 1	1101.	0.	0.	-1.	17. 7	-5.	2. 99	-1.
2223	11/20/76	415.	13. 6	1810.	2. 5	1107.	100.	100.	-1.		-5.	3. 52	-2.
2231	6/ 7/76	124.	4. 1	755.	3. 3	812.	57.	30.	-1.	17. 5	-5.	4. 32	-1.
2233	11/20/76	249.	18. 9	1086.	2. 4	816.	100.	0.	-1.		-5.	3. 38	-2.

TABLE B-3. Continued

SAMPLE NUMBER	CR UG/GM	CU UG/GM	PB UG/GM	MG MG/GM	MN UG/GM	HG UG/GM	NI UG/GM	K MG/GM	NA MG/GM	ZN UG/GM	SE UG/GM	ENDRIN NG/GM	LINDANE NG/GM
2111	5.	10.	-5.	1.	48.	-3. 00	3.	3.	1. 2	19.	-1.	-0. 03	1. 40
2113	4.	6.	-10.	2.	72.	-0. 05	6.	7.	0. 8	22.	-1.	-0. 03	0. 06
2121	3	7.	-5.	1.	43.	-3. 00	3.	3.	1. 2	18.	-1.	-0. 03	0. 40
2123	4.	8	-10.	1.	60.	-0. 05	-5.	8.	0. 8	32.	-1.	-0. 03	0. 08
2131	3.	9.	-5.	1.	42.	-3. 00	4.	3.	1. 0	21.	-1.	-0. 03	0. 80
2133	4.	4.	-10.	1.	53.	-0. 05	-5	6.	2. 2	21.	-1.	-0. 03	0. 26
2211	5.	11.	-5.	1.	69.	-3. 00	8.	4.	3. 3	37.	-1.	-0. 03	1. 00
2213	5.	8.	-10.	1.	80.	-0. 05	-5.	7.	3. 2	49.	-1.	-0. 03	0. 07
2221	4.	11.	-5.	2.	80.	-3. 00	6.	4.	2. 2	38.	-1.	-0. 03	2. 90
2223	8.	5.	-10.	1.	82.	-0. 05	-5.	4.	3. 4	25.	-1.	-0. 03	1. 00
2231	3	12.	-5.	1.	67.	-3. 00	6.	4.	2. 9	48.	-1.	-0. 03	0. 40
2233	4.	5.	-10.	1.	91.	-0. 05	6.	4.	3. 9	28.	-1.	-0. 03	0. 14

TABLE B-3. Continued

SAMPLE NUMBER	METHOXYCHLOR NG/GM	TOXAPHENE NG/GM	2,4-D NG/GM	SILVEX NG/GM
2111	-0.01	-0.1	-0.20	-0.10
2113	-0.01	-0.1	1.75	4.28
2121	-0.01	-0.1	-0.20	-0.10
2123	-0.01	-0.1	60.00	14.80
2131	-0.01	-0.1	0.50	-0.10
2133	-0.01	-0.1	-0.12	20.60
2211	-0.01	-0.1	0.20	0.20
2213	-0.01	-0.1	27.40	7.25
2221	-0.01	-0.1	0.60	0.30
2223	-0.01	-0.1	-0.12	6.90
2231	-0.01	-0.1	0.40	0.10
2233	-0.01	-0.1	63.50	26.40

GLOSSARY

Adsorption: A process in which soluble substances are attracted to and held at the surface of soil particles.

Advanced wastewater treatment: Additional treatment designed to reduce concentrations of selected constituents present in wastewater after secondary treatment.

Alkali soil: A soil with a high degree of alkalinity (pH of 8.5 or higher) or with a high exchangeable sodium content (15 percent or more of the exchange capacity) or both.

Aquiclude: A geologic formation which is porous and capable of absorbing water but will not transmit it rapidly enough to supply a well or spring.

Aquifer: A geologic formation or strata that contains water and transmits it from one point to another in quantities sufficient to permit economic development.

Consumptive use: Synonymous with evapotranspiration.

Conventional wastewater treatment: Reduction of pollutant concentrations in wastewater by physical, chemical, or biological means.

Drainability: Ability of the soil system to accept and transmit water by infiltration and percolation.

Effective precipitation: Precipitation that enters the soil and is useful for plant growth.

Evapotranspiration: The unit amount of water lost from a given area by transpiration, building of plant tissue, and evaporation from the soil surface, snow, or intercepted precipitation in a specified period of time.

Fixation: A combination of physical and chemical mechanisms in the soil that act to retain wastewater constituents within the soil, including adsorption, chemical precipitation, and ion exchange.

Groundwater: The body of water that is retained in the saturated zone that tends to move by hydraulic gradient to lower levels.

Groundwater table: The free surface elevation of the groundwater; this level will rise and fall with additions or withdrawals.

Infiltration: The entrance of applied water into the soil through the soil-water interface.

Infiltration-percolation: An approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores.

Irrigation: Application of water to the land to meet the growth needs of plants.

Land application: The discharge of wastewater onto the soil for treatment or reuse.

Loading rates: The average amount of liquid or solids applied to the land over a fixed time period, taking into account periodic resting.

Lysimeter: A device for measuring percolation and leaching losses from a column of soil; also a device for collecting soil water in the field.

Micronutrient: A chemical element necessary for plant growth in amounts below 1 mg/L.

Mineralization: The conversion of an element from an organic form to an inorganic form as a result of microbial decomposition.

Overland flow: Wastewater treatment by spray-runoff (also known as "grass filtration") in which wastewater is sprayed onto gently sloping, relatively impermeable soil that has been planted to vegetation. Biological oxidation occurs as the wastewater flows over the ground and contacts the biota in the vegetative litter.

Pathogenic organisms: Microorganisms that can transmit diseases.

Percolation: The movement of water through the soil pores once it has passed the soil-water interface.

Phytotoxic: Toxic to plants.

Primary effluent: Wastewater that has been treated by screening and sedimentation.

Refractory organics: Organic materials not removed in secondary treatment.

Ridge-and-furrow method: The surface application of water to the land through formed furrows; wastewater flows down the furrows, and plants may be grown on the ridge.

Saline soil: A nonalkali soil containing sufficient soluble salts to impair its productivity.

Secondary treatment: Treatment of wastewater by physical, chemical, or biological means such as trickling filters, activated sludge, or chemical precipitation and filtration.

Sewage farming: Originally involved the transporting of sewage to rural areas for land disposal. Later practice includes reusing the water for irrigation and fertilization of crops.

Soil texture: The relative proportions of the various soil separates--sand, silt, and clay.

Soil water: That water present in the soil pores in an unsaturated zone above the groundwater table.

Spraying: Application of water to the land by means of stationary or moving sprinklers.

Spray-runoff: See overland flow.

Tilth: The physical condition of a soil as related to its ease of cultivation.

Transpiration: The net quantity of water absorbed through plant roots and transpired plus that used directly in building plant tissue.

Viruses: Submicroscopic biological structures containing all the genetic information necessary for their own reproduction but dependent for reproduction upon living cells.